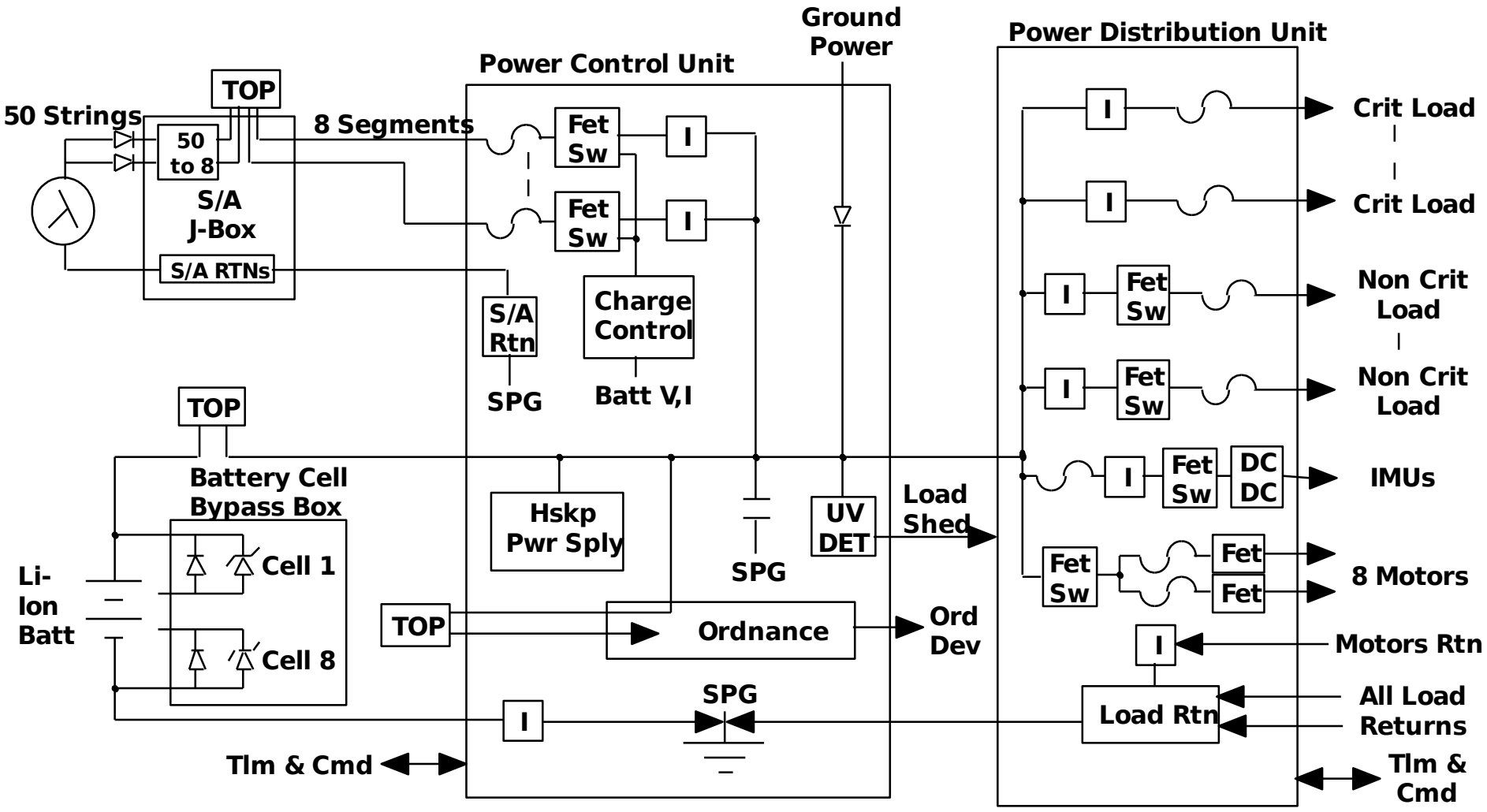
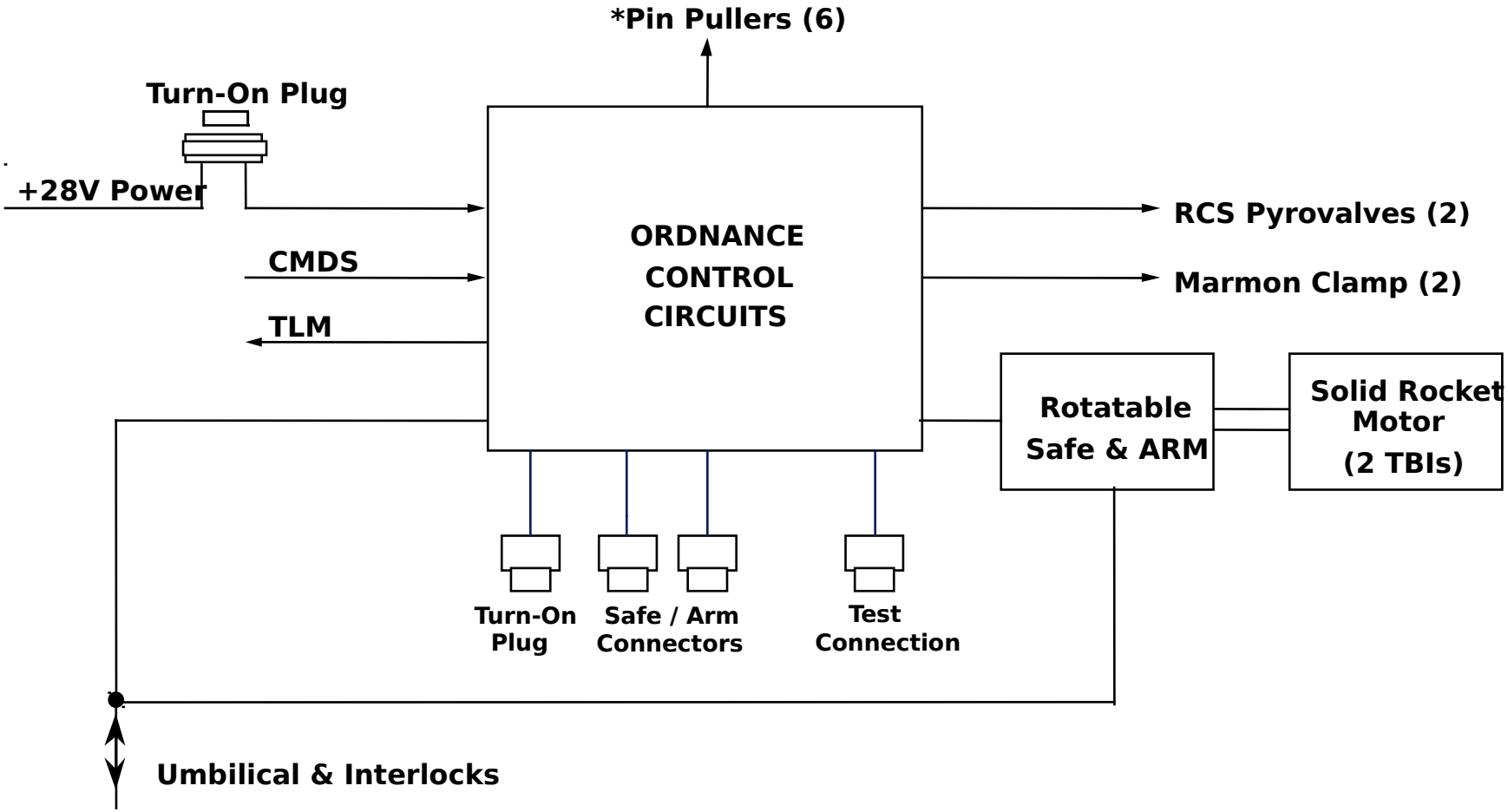
FAME Electrical, Ordnance & Harness Subsystems

Ralph Ruth
EPS Manager
NRL
202-767-6522
ruth@ssdd.nrl.navy.mil

FAME EPS Block Diagram



Ordnance Control Subsystem Interfaces



* Note: Pin Pullers Are Non-Explosive Devices

FAME EPS Top Level Requirements (1 of 2)

- **Energy Subsystems** — Supply Electrical Energy to All Spacecraft and Instrument During All Mission Phases
- **System Survival Be Fully Faults** — The EPS Shall Not Be Damaged by and Shall Recoverable From Operational and Electrical
- **Attitude the Disturbances** — The EPS Shall Minimize Torque Disturbances to Spacecraft Attitude
- **Telemetry Spacecraft** — EPS Health and Status Shall Be Provided to Telemetry
- **Control Motors Functions** — The EPS Shall Provide Control of All Spacecraft
- **Ordnance Activate All** — The EPS Shall Provide Electrical Energy to Ordnance Devices

FAME EPS Top Level Requirements (2 of 2)

- **Harness Connectivity the** — **The EPS Shall Provide Signal and Power Between All Spacecraft Subsystems and Between Instrument and Spacecraft Subsystems**
- **Environment Requirements** — **The EPS Shall Meet the Environmental Outlined in the FAME Test Plan NCST-TP-FM001**
- **Parts Qualified Program** — **EPS EEE Parts Shall Be Selected, Screened and per GSFC 311-INST-001 Document for a Level 2**

Derived Requirements (1 of 5)

Requirement	Implementation
Energy	***Generate Energy*** 515 W, at 30.4V, Body Mounted GaInP/GaAs/Ge Solar Array
	Store Energy 35Ah Li-Ion Battery
	Limit Battery DOD DOD <80% for 200 Cycles
	Charge Control Automatic Battery Charge Control With Selectable Battery Voltage Levels and Charge Current Rates Elimination of Excess Solar Array Energy
	Distribute Primary Power Battery Connected Directly to Critical Bus to Maintain Bus Voltage of 30 ± 6Vdc
	Distribute Secondary Power ± 5Vdc and ± 15Vdc to IMUs

Derived Requirements (2 of 5)

Requirement	Implementation
EPS Survival System	***Operational Faults*** Survive Operator EPS Command Misapplication
	Battery Overdischarge UnderVoltage Detection / Load Shed
	Battery Cell Equalization Battery Cell Bypass Circuit Limits Cell Divergence and Provides Cell Equalization
	Open Battery Cell Battery Cell Bypass Circuit Provides Charge and Discharge Current Path Around Open Cell
	Circuit Protection Fuses to Remove Harness/Load Shorts Double Insulate All Connections to the Critical Bus

Derived Requirements (3 of 5)

Requirement	Implementation
Attitude Disturbances	***Solar Cell String Design*** – Thermal Gradients Minimized – Magnetic Moments Minimized by Layout or Backwiring – Cell Array Flat to 2.5mm/2m Span Requirement
	Harness Design Power Lines and Return Lines Paired and Twisted
	Power Switching Solid State Switching to Replace Electromechanical Switching Wherever Disturbance Possible
Control Functions	***Motors*** Drive Circuits Providing Command Signals to: – Two CG Trim Mass Motors – Three Radiation Trim Tab Motors – Three Trim Area Motors

Derived Requirements (4 of 5)

Requirement	Implementation
Ordnance	***Safety*** **Design to Meet EWR 127-1 Requirements**
	Configuration **Ordnance Control Cards Contain:** – **Device Control Circuits** – **Device Firing Circuits**
	Isolation – **Source-to-Device Electrical Isolation** – **Source-to-Device Mechanical Isolation**
	Devices **EEDs/Non-Explosive Devices for:** – **Solid Rocket Motor Ignition** – **Spacecraft/Interstage Separation** – **RCS Activation** – **Trim Tab Release**
	EMI/EMC **Shielded Ordnance Lines, Filter Connectors**
Telemetry	**EPS Signals Provided** – **Analog Currents** – **Passive Temperatures** – **Analog Voltages** – **Digital Status**

Derived Requirements (5 of 5)

Requirement	Implementation
Harness	***Safety*** **Turn-on-Plugs for:** – **Solar Array** – **Ordnance** – **Battery** – **RCS**
	Minimize Magnetic Moments **Power and Return Lines Twisted and Paired**
	EMI/EMC **Power and High Speed Data Lines Separated**
	Voltage Drop **Wire Sizing to Meet GSFC311-INST-001, Rev A, Reqmts**
	High Speed Data Lines **Serial Bus and 1553 Compatible Lines**
Environment	***Temperatures*** – **EPS Electronic Boxes 0°C to 40°C** – **Solar Array -80°C to +100°C** – **Battery 0°C to 30°C** ***Vibration, Shock*** **Meet Limits As Stated in the FAME Design and Analysis Plan, NCST-D-FM017** ***Radiation*** **Meet Requirements As Stated in MRD Section 3.2.8.7.3 on Particle Radiation**
Parts	**All EEE Parts per GSFC-311-INST-001, Rev A** – **Selected Quality Level 2** – **Screened Quality Level 2**

FAME EPS Components

- Li-Ion Battery
  - 8 Cells
  - 35 Amp-Hour Capacity
- Solar Array
  - GaInP/GaAs/Ge Cells
  - 20 Cells per String
  - 50 Strings
- Power Control Unit
  - Battery Charging
  - Solar Array Control
  - Battery Interface
  - Undervoltage Detection
  - Ordnance Functions
- Power Distribution Unit
  - Unregulated Power to Loads
  - Regulated Power to IMUs
  - Motor Control
  - Signal Conditioning
- Battery Cell Bypass
  - Equalizes Cell Potential
  - Open Cell Bypass
- Solar Array J-Box
  - 50 Strings Into 8 Segments
- Spacecraft Harness

FAME Battery and Solar Array Sizing

- **Battery Capacity Is 35Ah**
  - **Supports Launch – TBD Minutes to Launch + 90 Minutes**
  - **Supports AKM Firing If Solar Array Is Pointed Away From Sun**
  - **Supports Maximum Eclipse Time**
- **Solar Array EOL Power Is 515 Watts at 30.4V**
  - **Supports Total Observatory Power Requirements + 20% Contingency**
  - **Sized With Temperature, Radiation, Life and Sun Angle Taken Into Account**

FAME EPOS Major Milestones

- **Solar Array Delivery** — **8 Sept 2003**
- **Battery + BCB Delivery** — **28 Nov 2003**
- **Electronic Box Deliveries**
  - **PDU, Brassboard** — **15 Aug 2002**
  - **PCU, Proto-Flight** — **12 May 2003**
  - **PDU, Proto-Flight** — **12 May 2003**
  - **Solar Array J-Box, Proto-Flight** — **1 Nov 2002**
- **Flight Harness Completion** — **15 Aug 2002**

FAME EPS Electronics Status

Electronic Box	Drawing Status	Breadboard Status
Power Control Unit	All 10 Preliminary Daughterboard Schematics Complete	60% of Circuits Tested/in-Test
Power Distribution Unit	All 9 Preliminary Daughterboard Schematics Complete	50% of Circuits Tested/in-Test
Battery Cell Bypass Box	Breadboard Schematic Complete	100% of Circuits in Test
Solar Array J-Box	In Progress	Not Required

Procurement Status of EPS Long Lead Items

Item	Status	Est. Delivery Time ARO
Solar Array	Not Ordered, ROMs Received	12 Months
Battery	Not Ordered, ROMs Received	5 – 12 Months
DC-DC Converters	Not Ordered, Manufacturer Identified	6 – 12 Months

FAME EPS Major Trade Studies

Closed Trades	Decision
Battery Chemistry Lithium-Ion vs Nickel-Hydrogen	Lithium-Ion
Heater Control Closed Loop vs Open Loop	Open Loop
Ordnance Control Electronics Separate Box vs Contained Within PCU	Within PCU
Redundancy Redundant vs Non-Redundant Electronics	Non-Redundant
Ongoing Trades	
None	

Fame EPS Test Matrix

Component	200 HR Burn-In	Thermal Cycle	Random Vibration	Acoustic Vibration	EMI/EMC	Thermal Cycle
PCU	Yes	Yes	Yes	No	Yes	Yes*
PDU	Yes	Yes	Yes	No	Yes	Yes*
BCB	Yes	Yes	Yes	No	Yes	Yes*
S/A J-BOX	Yes	Yes	Yes	No	No	Yes*
Solar Array	No	No	No	Yes	No	Yes
Battery	No	Yes	Yes	No	No	Yes*

* At System Level

Fame EPS Open Issues

- **None Identified At PDR**

Back-Up

Fame EPOS Peer Review

- **Peer Review Held on 10/10/01**

- **Peer Review Team**
  - **Karen Stewart - NASA Goddard Power Systems Engineer**
  - **Joseph Bolek - NASA Goddard Systems Engineer**
  - **Dr George Dakermanji - Johns Hopkins Applied Physics Lab, Supervisor of Power Systems Section**

- **Resulting Action Items**
  - **Resize the Solar Array Taking Into Account Any Degradation Effects of Radiation in the GTO Orbit**
  - **Calculate Solar Array Power Output Delta for Any Temperature Variations Across the Array**
  - **Recalculate Solar Array Power Margin Upon Exiting Eclipse**
  - **Re-Examine Heater Power Profile in Eclipse**

United States Naval Observatory

LOCKHEED MARTIN

Energy Sources & Storage Systems

J. Christopher Garner

Electrical Power Subsystem Engineer

NRL

202-767-9075

garner@ssdd.nrl.navy.mil

Energy Sources/Storage Requirements

- **Provide Electrical Power to All FAME Subsystems for All Mission Phases**
  - **Observatory in Sun - Solar Cell Array to Convert Sunlight to DC Power**
  - **Observatory in Eclipse - Electrochemical Battery to Provide DC Power**
- **Support 5 Year Mission in GEO Orbit**
  - **Solar Array - Use Radiation Tolerant Solar Cells, Coverglass Shielding to Minimize Radiation Degradation**
  - **Battery - Use Technology to Meet Support 200 Charge/Discharge Cycles Over 5 Year GEO Mission**
- **Minimize Magnetic Moment Induced by EPS Components**
  - **Solar Array - Use Backwiring of Strings to Cancel Magnetic Moments**
  - **Battery - Harness Routing to Minimize Magnetic Moments**

FAME Power Requirements

Mission Phase	Launch	GTO	Sub Sync	GEO-Early GEO	GEO-Science	GEO-Science	Safe-Hold M
Instrument State	Off	Off	Off	Boot, Standby	Boot, Stndby, FO	Opus	Survival
Spacecraft Bus							
CTDH	27.10	39.50	39.50	39.50	39.50	39.50	24.10
ADCS	1.25	21.25	31.25	45.55	35.55	35.55	25.55
RF	8.00	45.00	45.00	45.00	45.00	45.00	45.00
EPS	15.00	38.00	38.00	38.00	90.50	90.50	18.00
TCS	0.00	64.50	64.50	64.50	64.50	64.50	64.50
Spacecraft Power By Operational Phase	51.35	208.25	218.25	232.55	275.05	275.05	177.15
20% Spacecraft Contingency	10.27	41.65	43.65	46.51	55.01	55.01	35.43
Total Spacecraft Power By Operational Phase	61.62	249.90	261.90	279.06	330.06	330.06	212.58
Instrument	0.00	60.00	60.00	135.50	135.50	165.50	55.00
20% Instrument Contingency	0.00	12.00	12.00	27.10	27.10	33.10	11.00
Total Instrument Power By Operational Phase	0.00	72.00	72.00	162.60	162.60	198.60	66.00
Total Observatory Power W/Contingency	61.62	321.90	333.90	441.66	492.66	528.66	278.58
BOL Solar Array Power Out @ 30.4 V	0.00	388.50	525.00	525.00	525.00	525.00	?
EOL Solar Array Power Out @ 30.4 V			515.00	515.00	515.00	515.00	
BOL S/A Margin (W)		66.60	191.10	83.34	32.34	-3.66	
BOL S/A Margin (%)		21%	57%	19%	7%	-1%	
EOL S/A Margin (W)			181.10	73.34	22.34	-13.66	
EOL S/A Margin (%)			54%	17%	5%	-3%	

Solar Array Sizing (1 of 2)

- **1 x 10^{14} 1 mev Equivalent Electrons Fluence for 5 Year GEO Orbit, 6 Mil Coverglass, Infinite Backshielding**
  - **Radiation Degradation Factors**
  - **I_{sc}, I_{mp} 1**
  - **V_{oc}, V_{mp} 0.96**
- **On-Orbit Temperature 95°C**
  - **Temperature Coefficient**
    - **Isc (µA/°C) 2.72E-04**
  - **Imp (µA/°C) 2.18E-04**
  - **Voc (mV/°C) -4.20E-03**
  - **Vmp (mV/°C) -4.60E-03**
- **Sun Angle 35 ± 5°**
  - **Cosine Factor 0.766 (40° Worst Case)**
- **$V_{Solar\ Array} = V_{Battery} + V_{Diode} + V_{Wireharness} = 35.5V$**

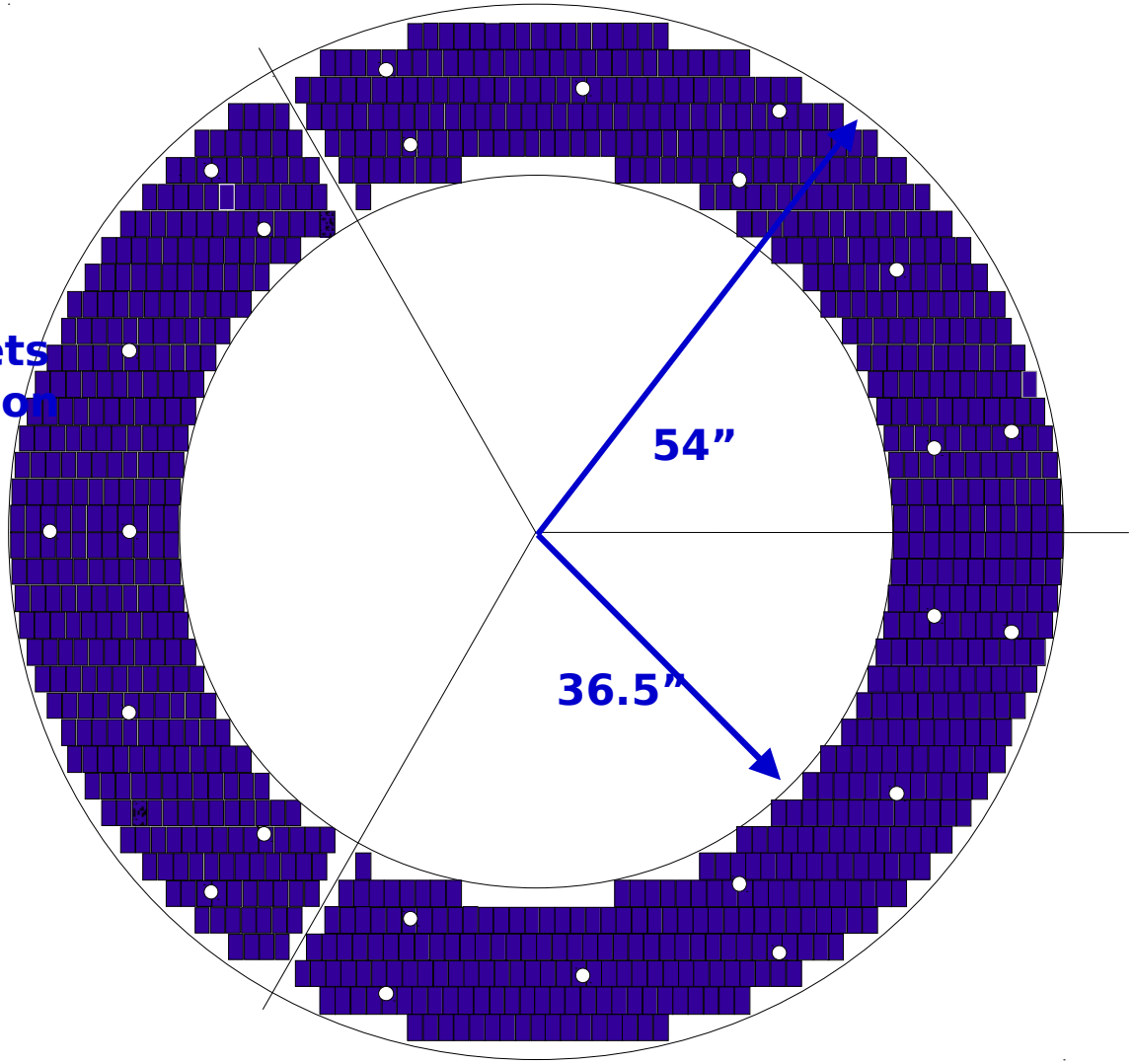
Solar Array Sizing (2 of 2)

- **Number of GaInP/GaAs/Ge Solar Cells in Series Required = 20**
- **Number of Solar Cell Strings in Parallel = 50**
- **Number of Strings/Segment = TBD**
- **BOL Solar Array Power = 525W @ 30.4V**
- **EOL Solar Array Power = 515W @ 30.4V**

Preliminary Solar Cell Layout

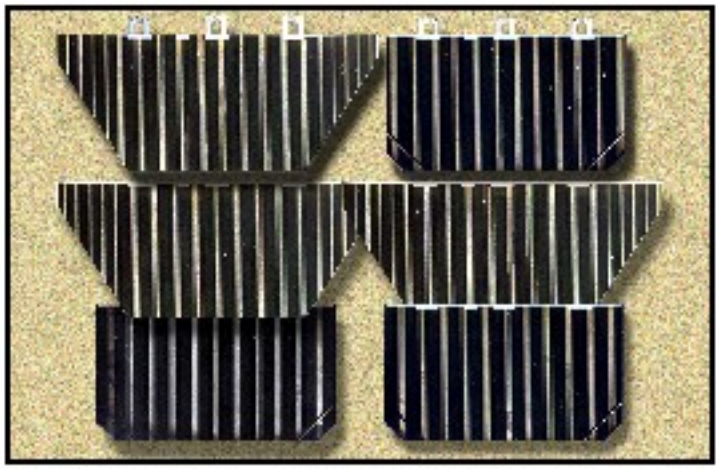
(3) Substrates:

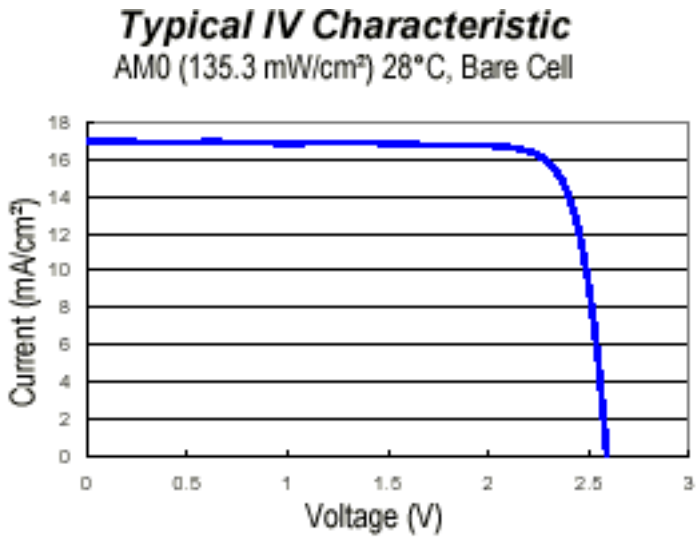
- **Graphite Epoxy Facesheets**
- **Co-Cured Kapton Insulation**
- **Aluminum HoneyComb**

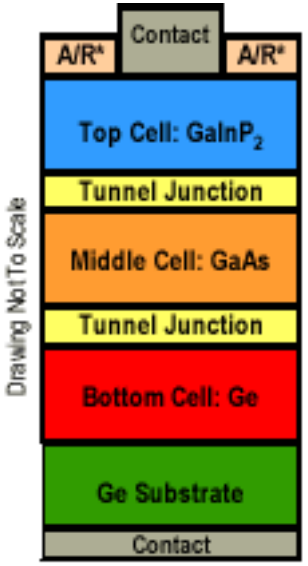


26.8% Efficient Solar Cells

- GaInP2/GaAs/Ge Solar Cells
- Width (cm) 3.95
- Length (cm) 6.89
- Isc (A) 0.460
- Imp (A) 0.435
- Voc (V) 2.56
- Vmp (V) 2.23







*A/R: Anti-Reflective Coating

Triple Junction Solar Cell Comparison

Parameter	Spectrolab	Tecstar	Emcore
Width	3.95	3.84	3.90
Length (cm)	6.89	6.32	7.05
Area (cm^2)	27.22	24.26	27.50
Thickness (mil)	5.5	5.5	6.0
Mass (grams)	1.634	2.230	2.400
Voc (V)	2.56	2.56	2.565
Vmp (V)	2.23	2.25	2.27
Isc (A)	0.460	0.408	0.445
Imp (A)	0.435	0.383	0.427
Efficiency (%)	26.8	26.5	26.0

Battery Trade-Study

	NiCd	IPV NiH2	CPV NiH2	SPV NiH2	SPV NiH2	Li-Ion
Number of Batteries	1	1	1	1	2	1
Number of Cells	23	23*	23*	22	22	8
Capacity (Ah)	30	30	30	30	15	30
Mass (kg)	30.91	22.63	18.33	21.06	19.96	8.35
Volume (cm3)	3.40E+04	3.92E+04	2.81E+04	2.06E+04	3.30E+04	3.16E+03
Specific Energy (Wh/kg)	29.12	39.77	49.10	42.74	22.55	100
Energy Density (WH/cm3)	0.0265	0.0230	0.0321	0.0437	0.0136	0.266

* Includes 1 Spare Cell

Energy Storage Sizing

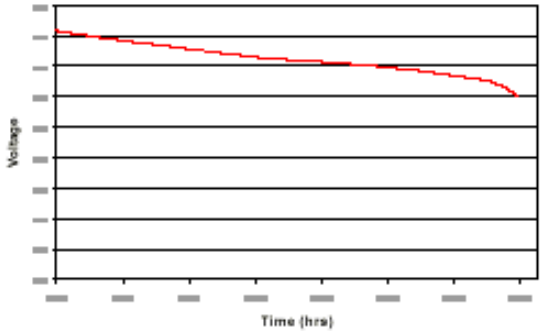
- **Battery Must Support TBD Minutes Before Launch + 90 Minutes Until Fairing Separation and Sun Orientation**
- **Battery Must Support Apogee Kick Motor Firing If Solar Array Is Pointed Away From Sun**
- **FAME Observatory Will Experience Two Eclipse Seasons Every Year**
  - **20 Day Duration**
  - **Maximum Eclipse Is 70 Minutes on Day 10**
- **Capacity Required for Maximum Eclipse**
  - **(468W/28V)*(70/60) = 19.50 Ampere-Hours**
  - **Maximum Depth of Discharge Allowed 80%**
  - **Battery Capacity = 19.50/0.8 = 24.38 Ampere-Hours**
- **Capacity Required for AKM Firing**
  - **If Sun Angle $\geq$ 90°, Battery Can Support 1.5 Hours at 360 W**
  - **Increase Battery Capacity to 35 Ah, Battery Can Support 2.18 Hours**
- **Baseline Battery Capacity Is 35Ah**

Lithium Ion Battery Choice

- **Li-Ion Has Highest Specific Energy, Is the Lowest Mass Choice**
- **8 Battery Cells Compared to 23 for Nickel Cadmium or Nickel Hydrogen**
- **Variety of Manufacturers Available:**
  - **Eagle Picher**
  - **Yardney**
  - **MSA**
  - **SAFT**
  - **COMDEV**
  - **Melco**
- **Charge/Discharge Cycle Life Data Available From NASA, Air Force, NRL, and Cell Manufacturers**

Lithium Ion Battery Cells

Voltage vs. Time
Discharge Profile of 35Ah
Lithium-ion Cell



Performance Data

Cathode	:	Lithiated Nickel Cobalt Oxide	Nominal Voltage	:	3.6V
Anode	:	Graphite	Nominal Weight	:	870 gms
Electrolyte	:	EC:DMC:DEC	Cycle Life	:	> 800 Cycles
Nominal Capacity	:	35Ah @ C/5	Volumetric ED	:	335 Wh/l
Pulse Current Capability	:	150 Amp (5C)	Gravimetric ED	:	145 Wh/Kg
Sustained Maximum Current	:	70 Amp	Coulombic Efficiency	:	99%
Dimensions	:	3.74" x 1.096" x 5.500"	Fade Rate	:	0.02%/Cycle

Yardney Technical Products, Inc.
82 Mechanic Street, Pawcatuck, CT 06379 (860) 599-1100 – Fax: (860) 599-3903
http:\\www.yardney.com

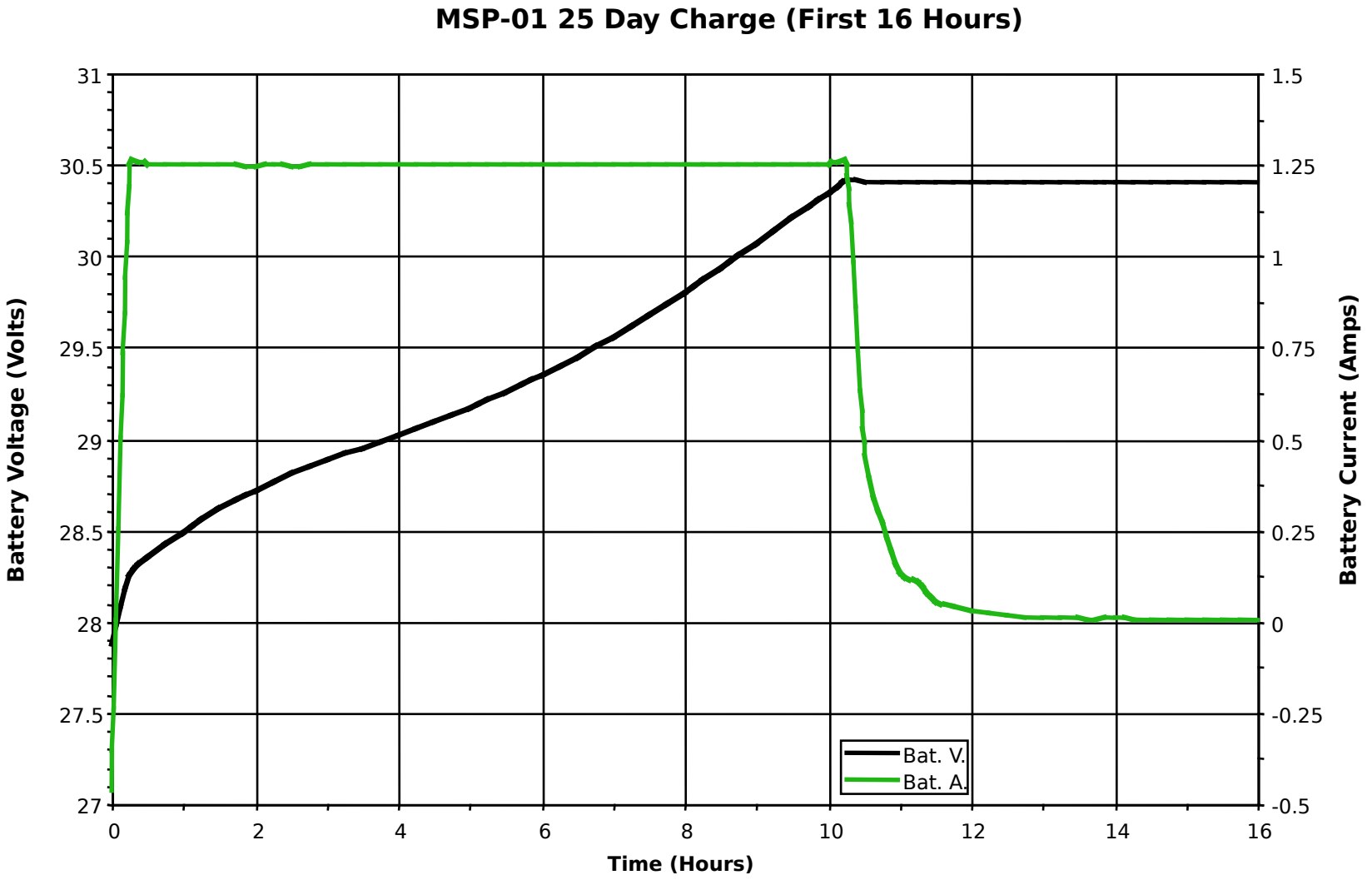
Lithium Ion Risk Reduction

- **Yardney/JPL MSP-01 Battery**
- **30-35 Ah Li-Ion Battery Not Flown When Mission Was Cancelled**
- **On Loan to NRL From NASA/LM Denver**
- **NRL to Conduct an Accelerated GEO Cycling Program**
  - **Obtain 5 Years Data in 2.5 Years**

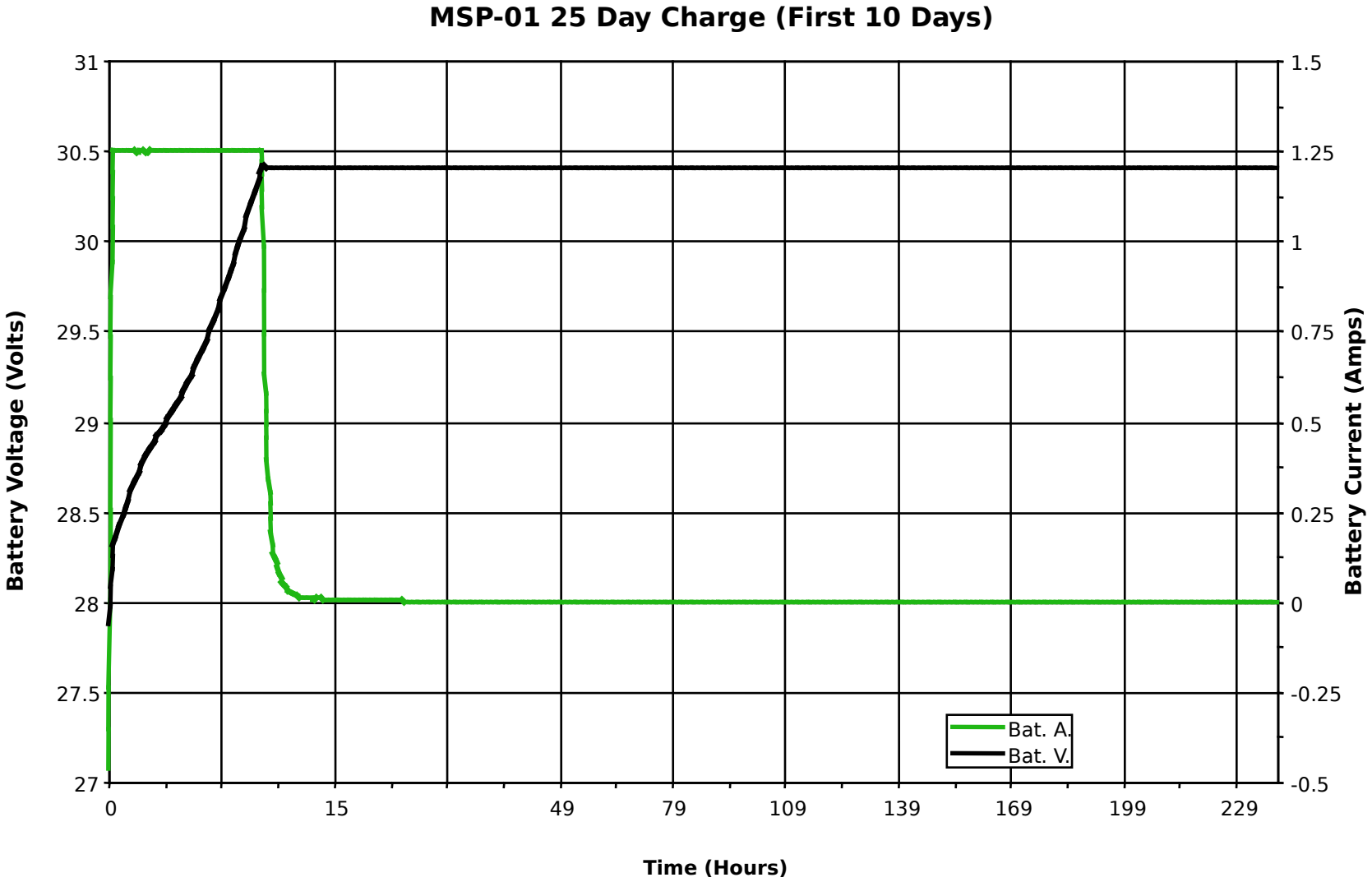
Yardney Technical Products, Inc.
82 Mechanic Street, Pawcatuck, CT 06379 (860) 599-1100 – Fax: (860) 599-3903
http:\\www.yardney.com

NRL MSP-01 Accelerated GEO Test Results

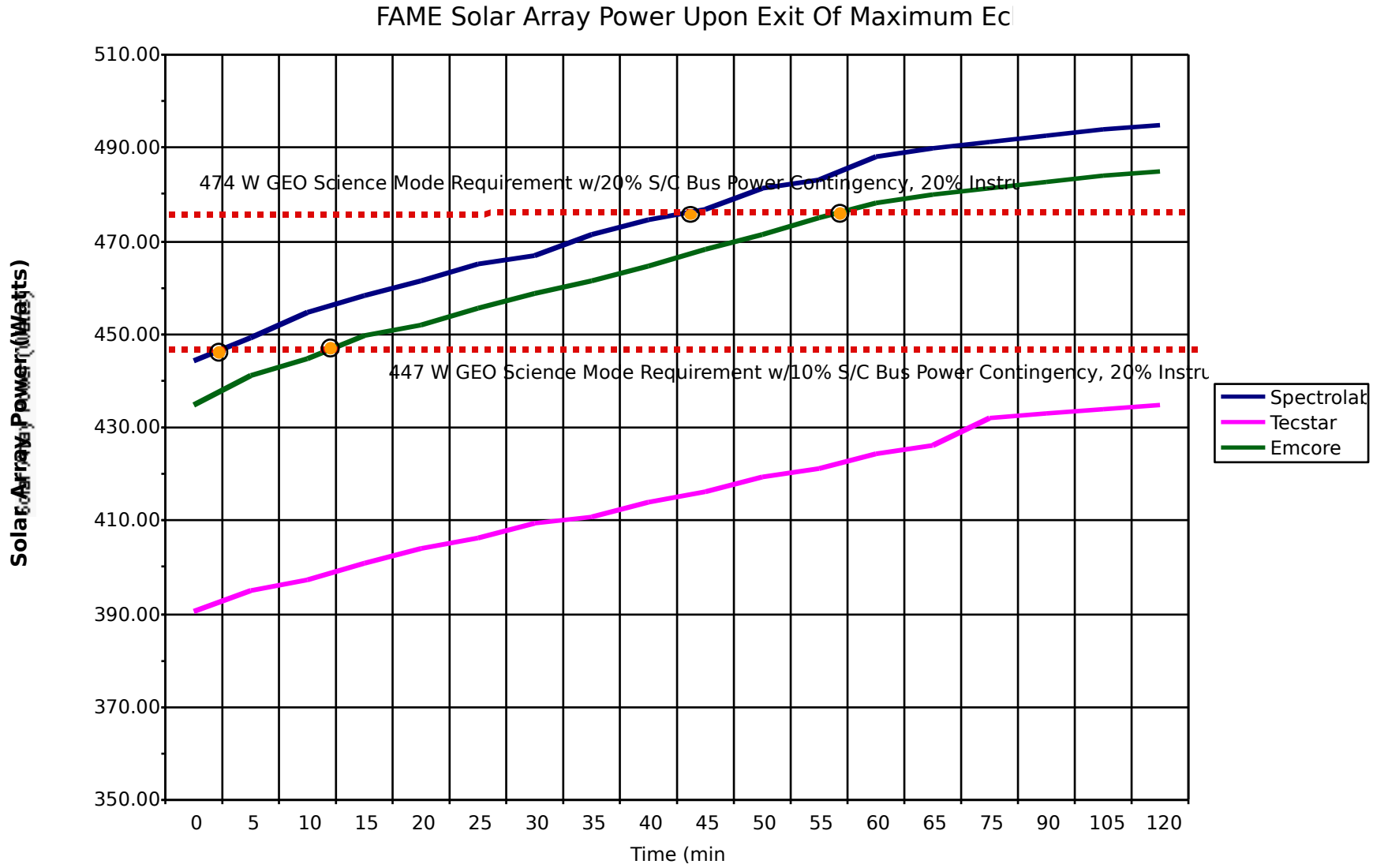
NRL MSP-01 Accelerated GEO Test Results



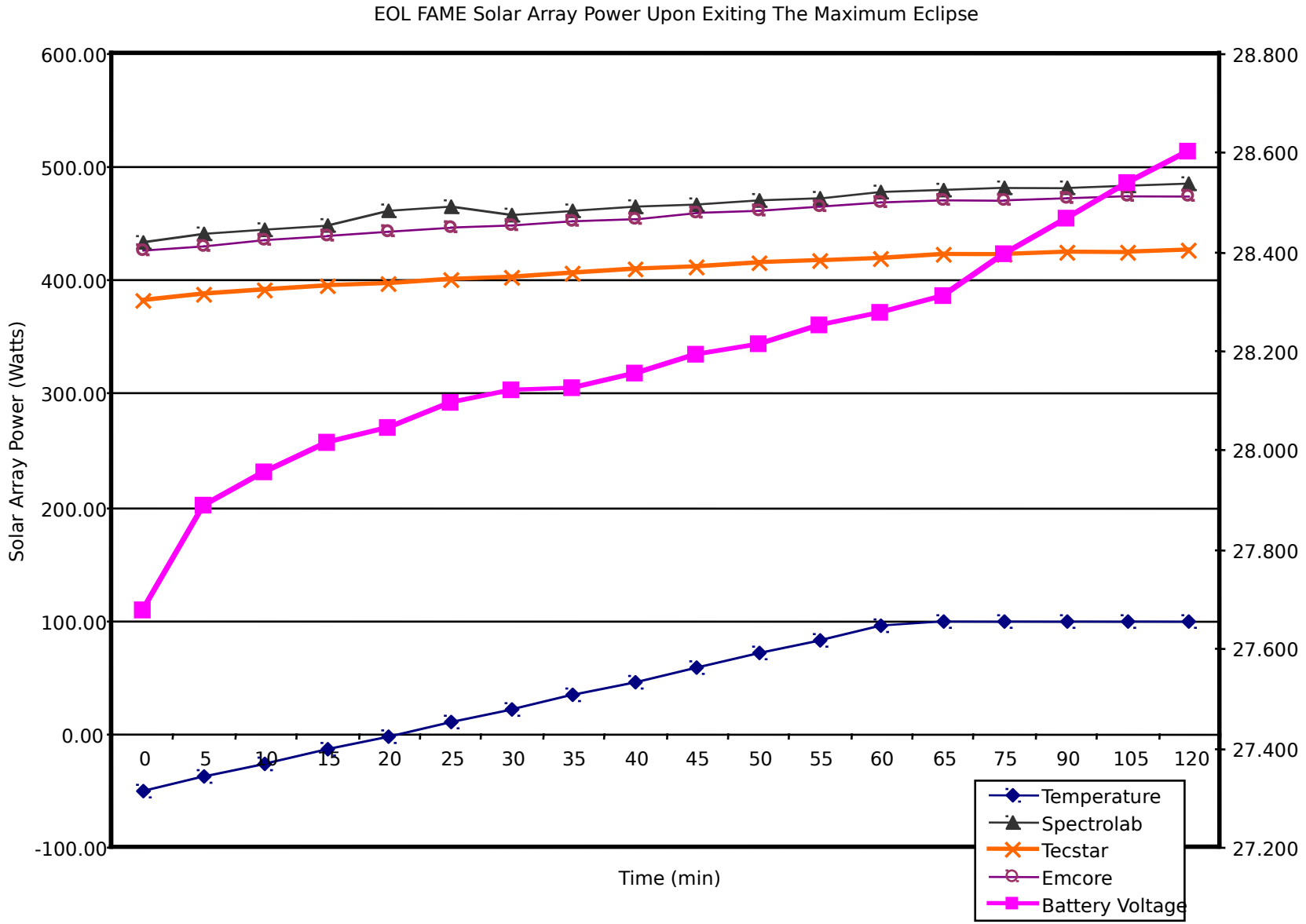
NRL MSP-01 Accelerated GEO Test Results



Solar Array BOL Power Upon Maximum Eclipse Exit

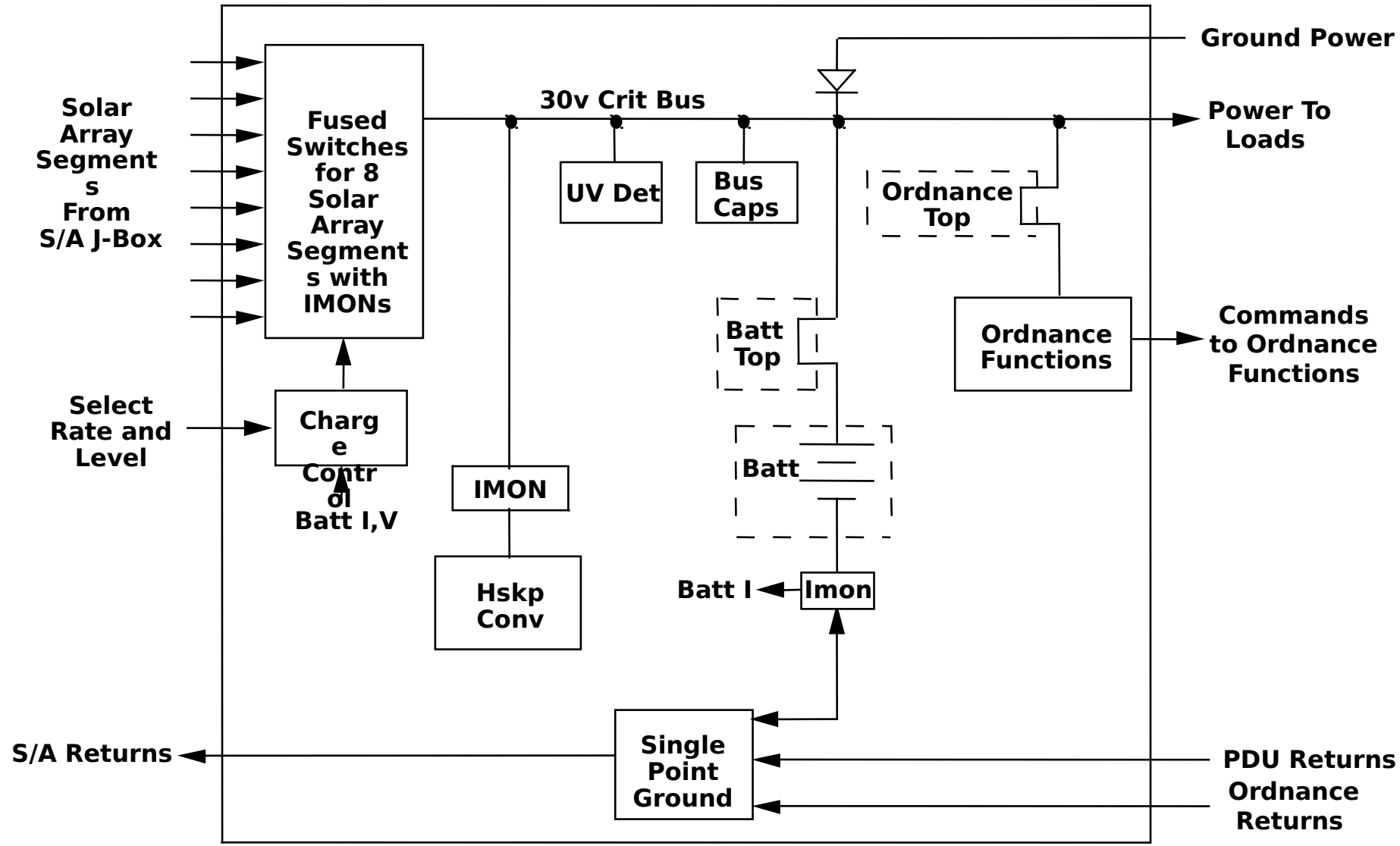


Solar Array EOL Power Upon Maximum Eclipse Exit



Power Control Unit

FAME EPS Power Control Unit



PCU Features

- Creates 30+/-6Vdc Critical Bus to Provide Power to All Loads
- Modulates S/A Current via Battery Charge Controller
- Charges Battery by Constant Current/Constant Voltage Modes
- Provides Undervoltage Detection to Protect Battery
- Contains All Ordnance Control Circuits
- Provides for T-O Umbilical Power Input
- Contains Single Point Ground for Entire Spacecraft
- Provides Regulated ±15Vdc to Power Distribution Unit and Battery Cell Bypass Unit
- Monitors Housekeeping Parameters such as Currents, Voltages and Status

FAME Charge Control Subsystem

FAME Charge Control System Heritage

- **Clementine (Lunar Mapping Spacecraft)**
- **ISS ICM (Reboost, Attitude Control, Contingency)**

FAME Comparison with ICM

ICM: **LEO, 1.5 Hour Period/0.5 Hour Eclipse**

- **(2) 32 AH NiCd Batteries**
- **Constant Current/V-T Charge Control**
- **C/2 Maximum Charge Rate**

FAME: **GEO, 24 Hour Period/70 Minute Eclipse**

- **35 AH Li-Ion Battery (8-Cell)**
- **Constant Current/V-Level Charge Control**
- **C/20 Maximum Charge Rate**

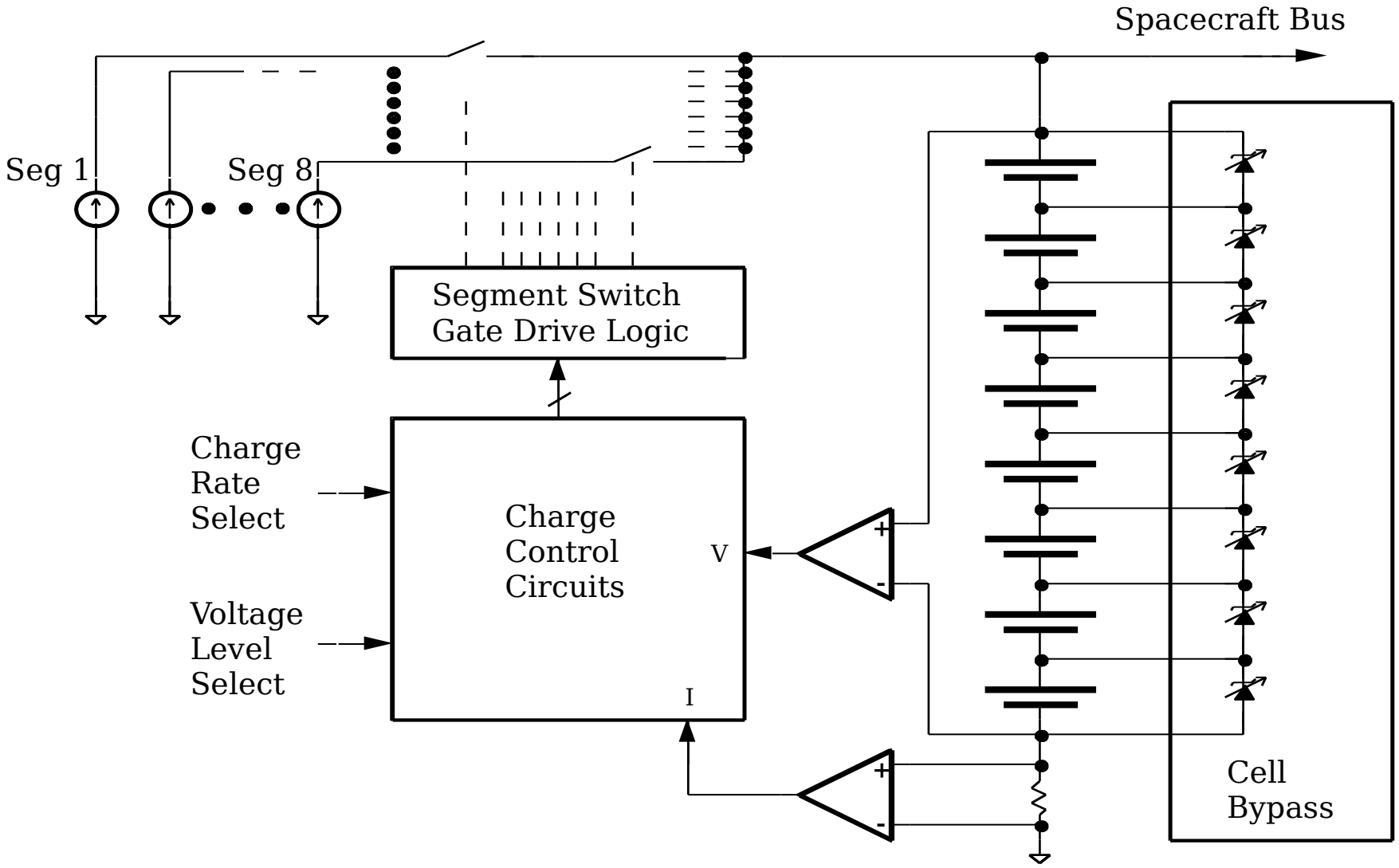
FAME Charging System Requirements (1 of 2)

- **Charge Single 35 Ah Li-Ion Battery:**
  - **Provide Controlled-rate Charging With Voltage Limit (Taper Charge):**
    - **4 Selectable Rates: C/20 Nominal, C/50, C/100, C/200**
    - **4 Selectable Maximum Voltage Levels: 32.8v, 32.0v, 31.2v, 30.4v**
- **Provide Automatic Switchover From Constant Current to Constant Voltage Mode**
- **Provide Maximum Charge Rate, C/20, on Undervoltage Detection**

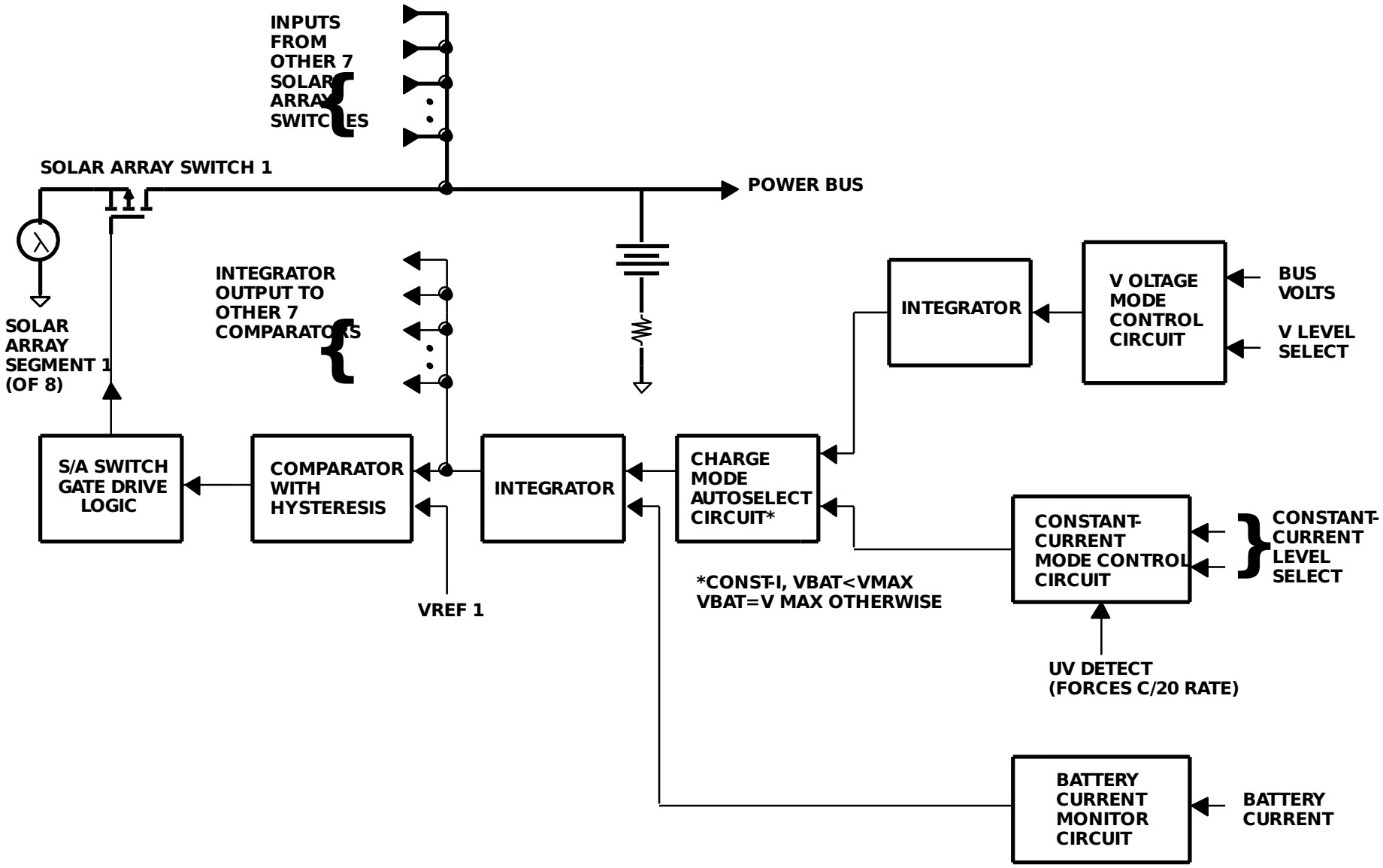
FAME Charging System Requirements (2 of 2)

- **Reject Excess Solar Array Energy**
- **Prevent Li-ion Battery Overcharge/Cell Imbalance**
  - **Prevent Cell Imbalance/Overcharge Through Selective Cell Bypassing:**
    - **4 Selectable Bypass Voltage Levels**

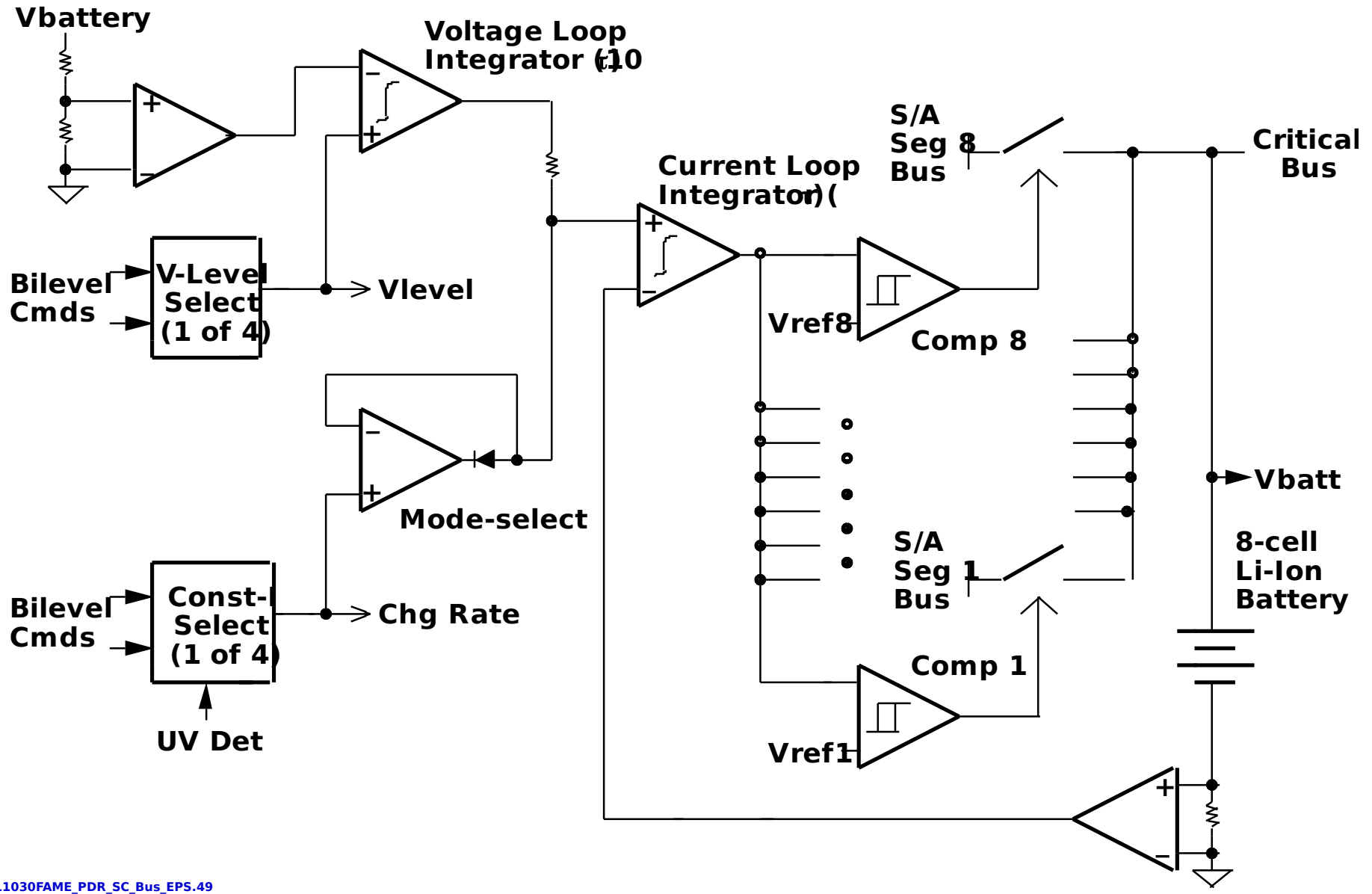
FAME Charging System Concept



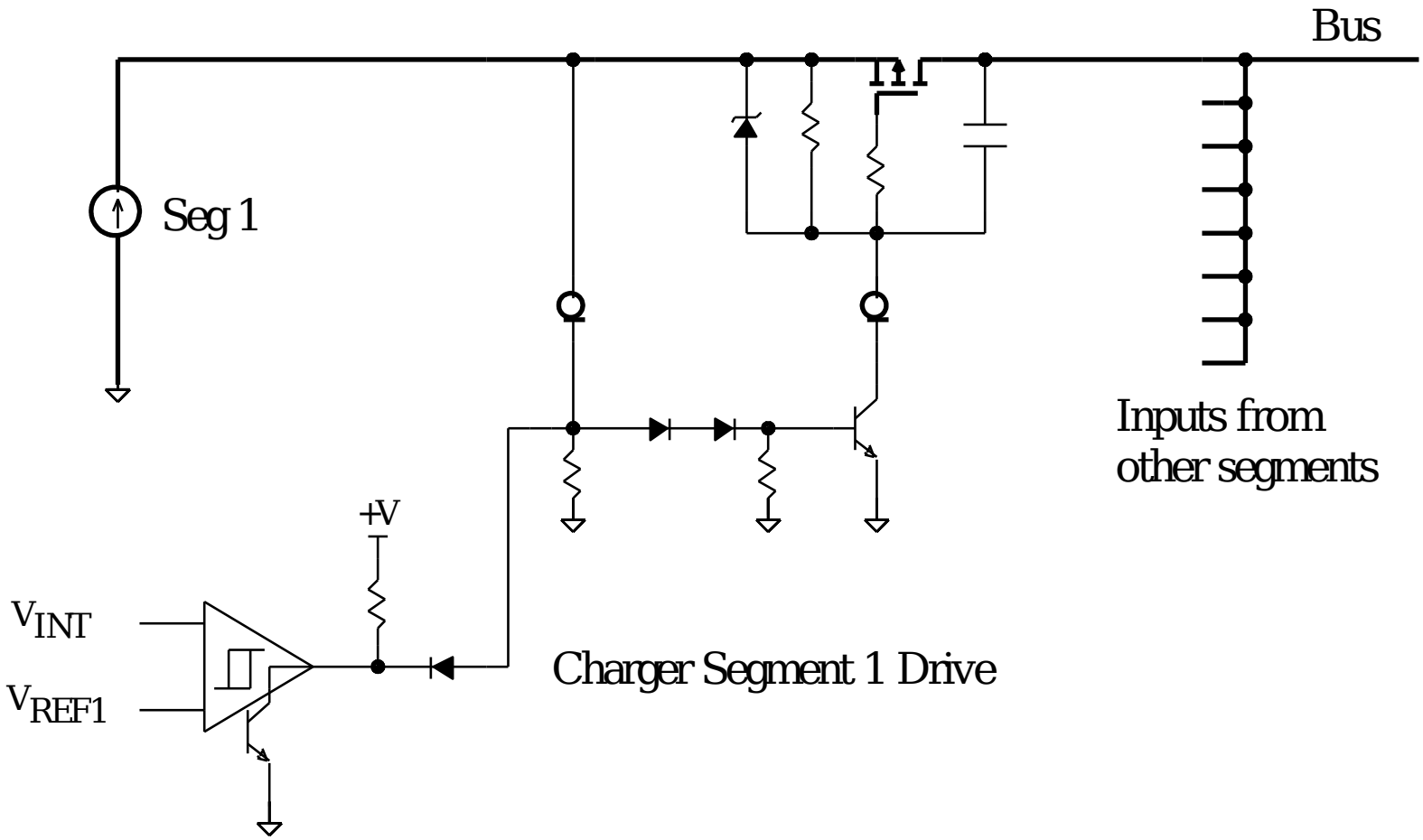
FAME Charge Control Block Diagram



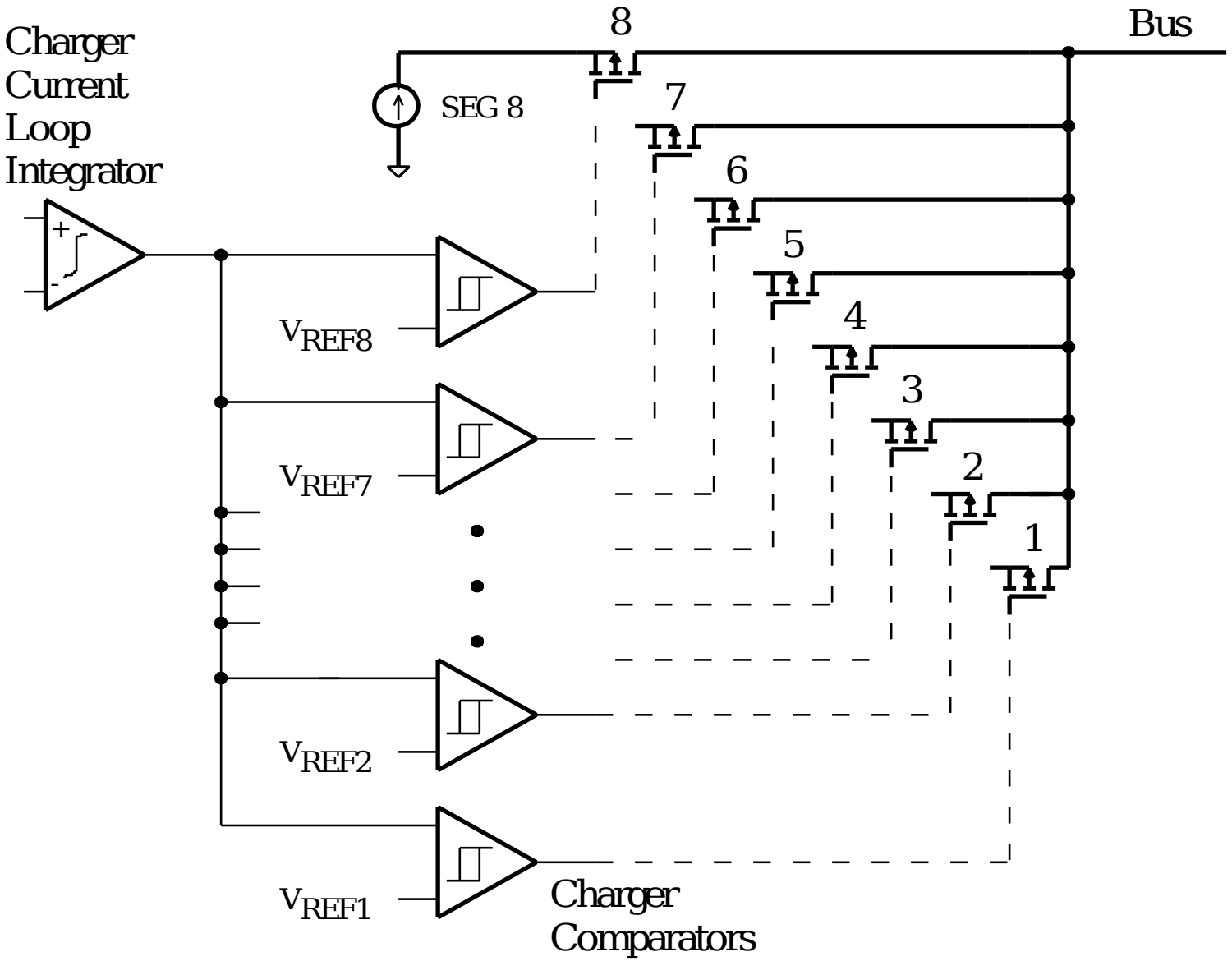
FAME Charger Detail



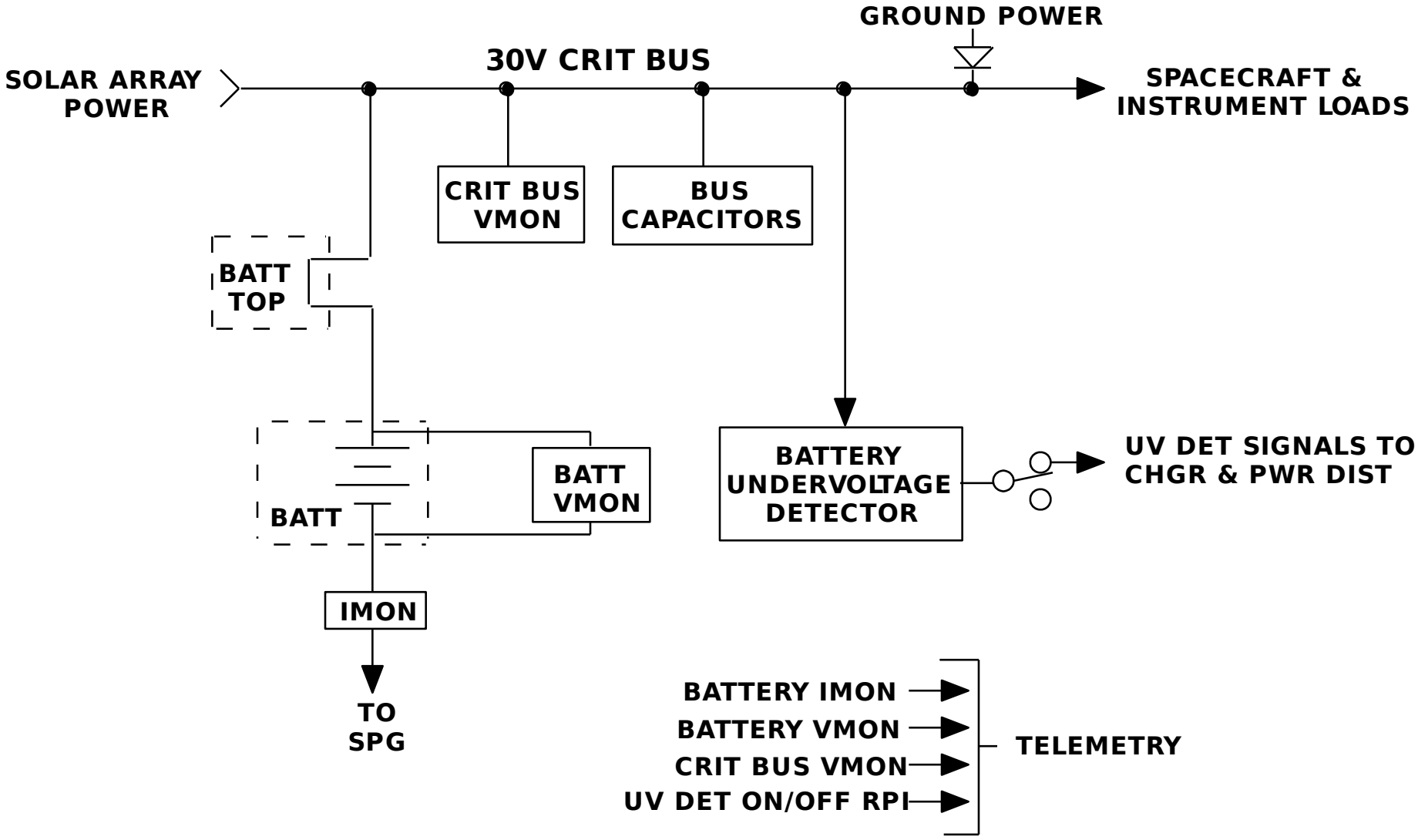
Charger Solar Array Gate Drive Detail



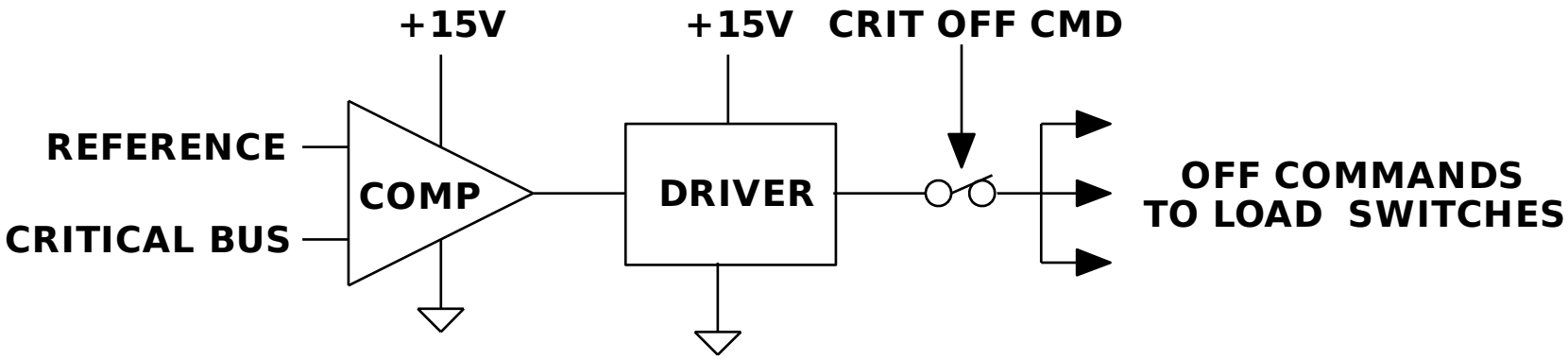
FAME Solar Array Segment Control



Battery/UV DET Interface Circuits

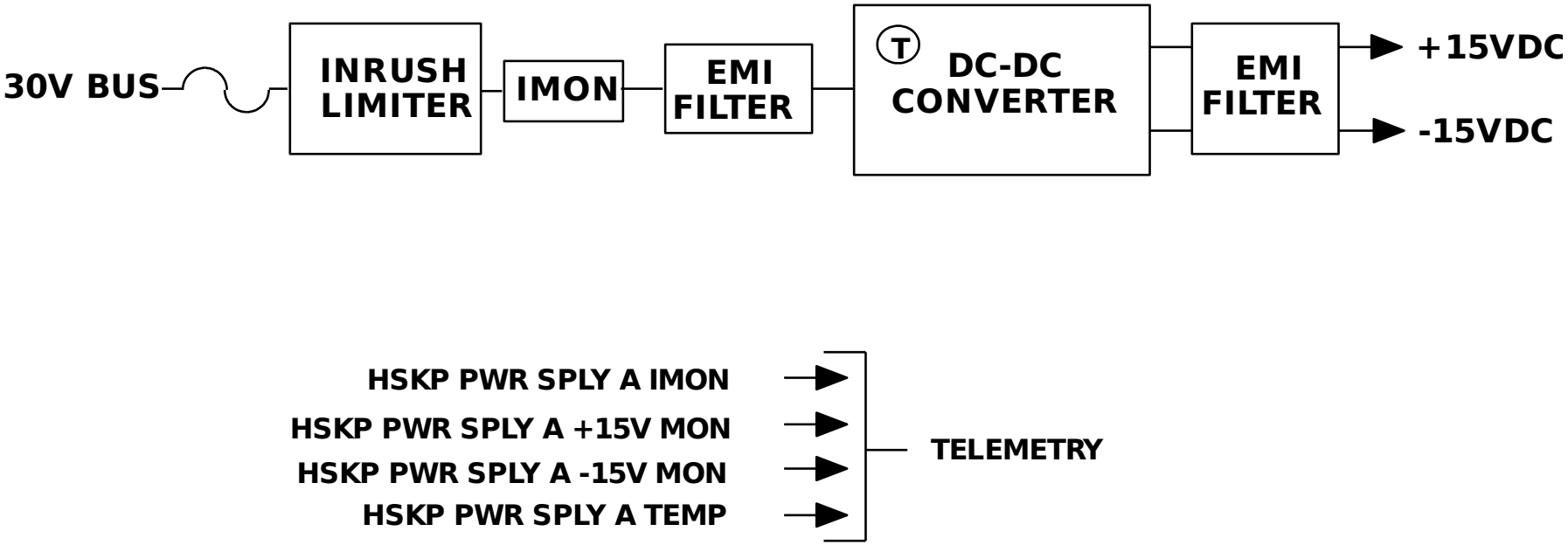


Undervoltage Detector Block Diagram



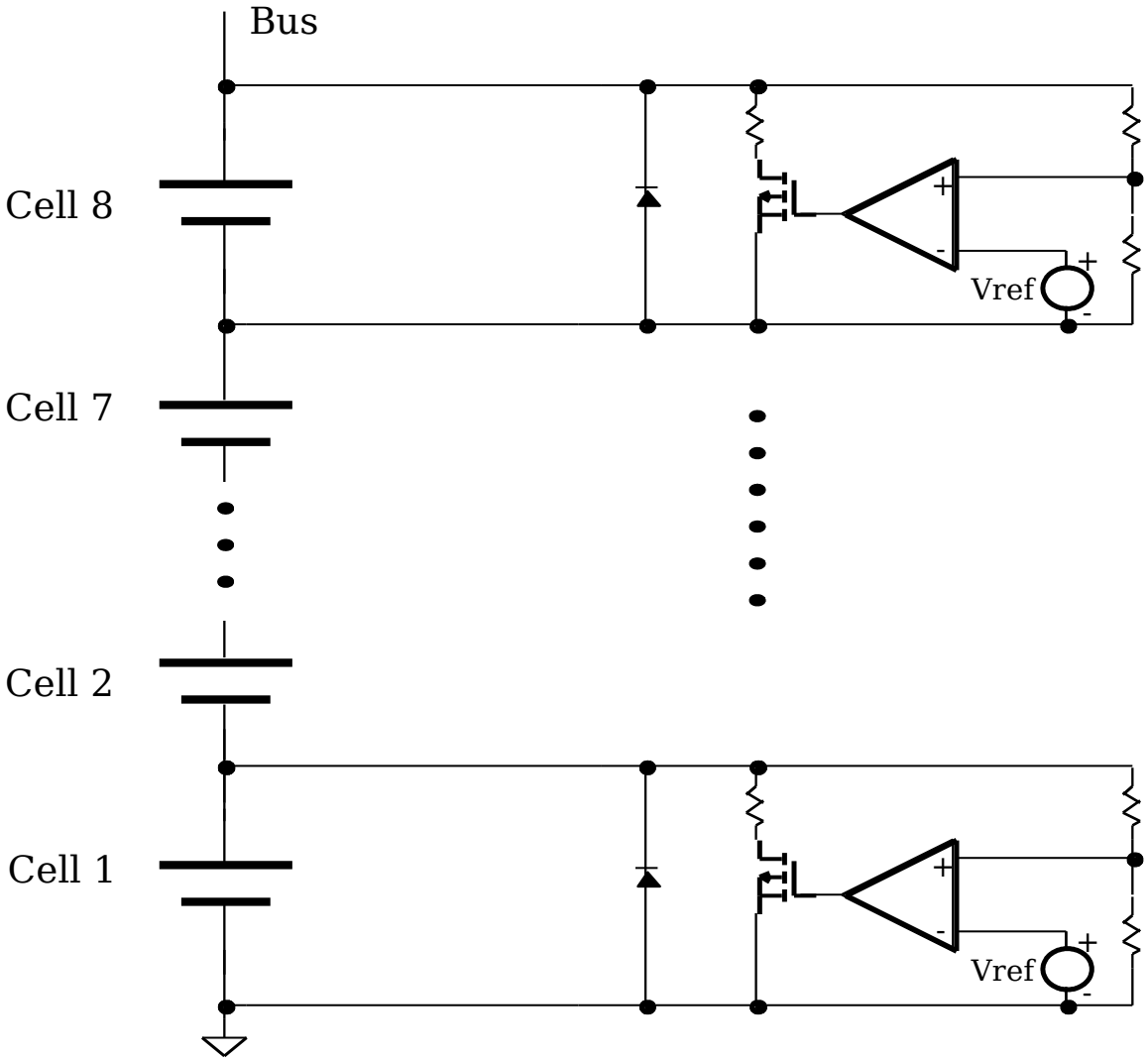
-- TRIPS AT 24.5V +/-.25V

PCU Housekeeping Power Supply Block Diagram



Battery Cell Bypass Unit

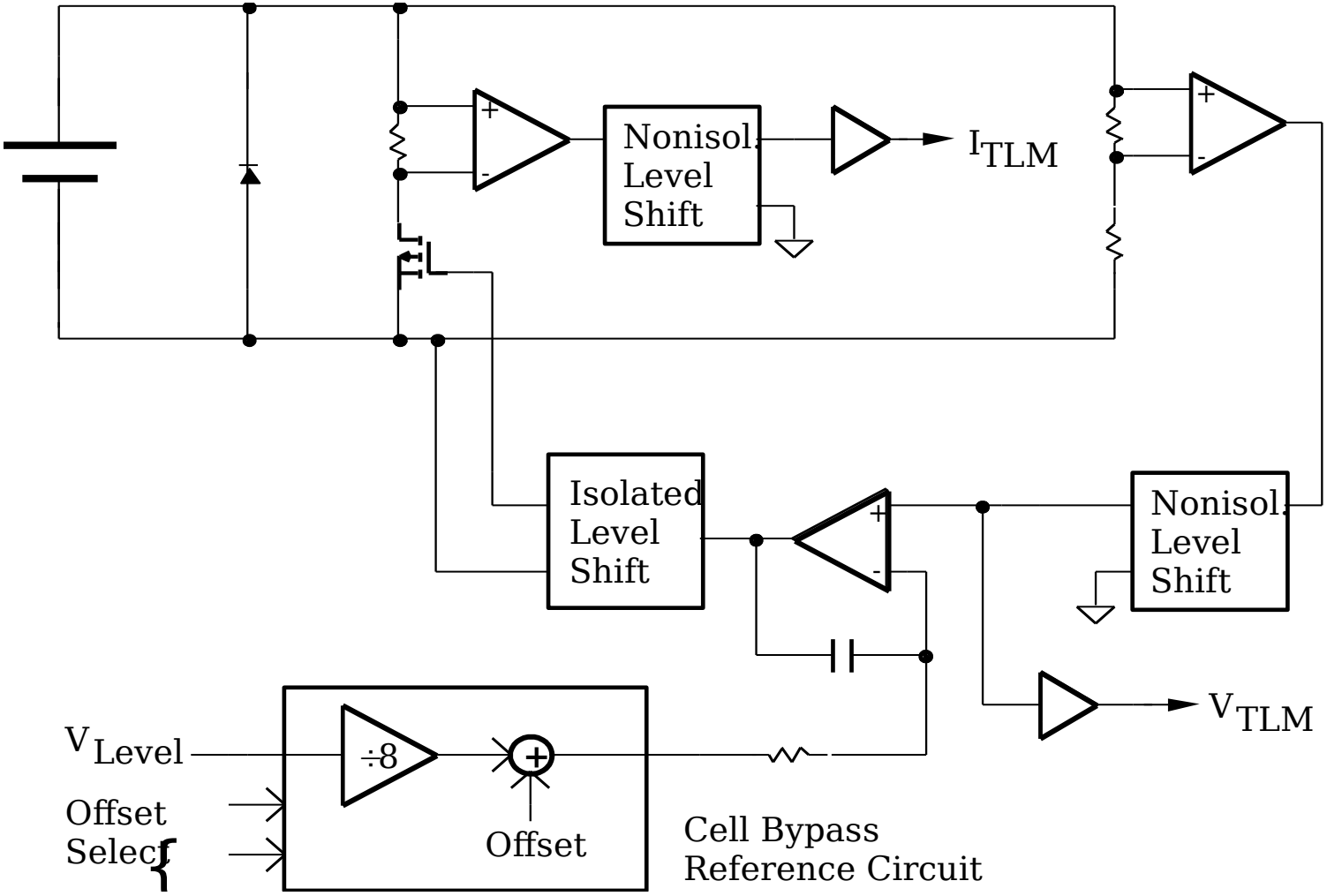
FAME Cell Bypass Concept



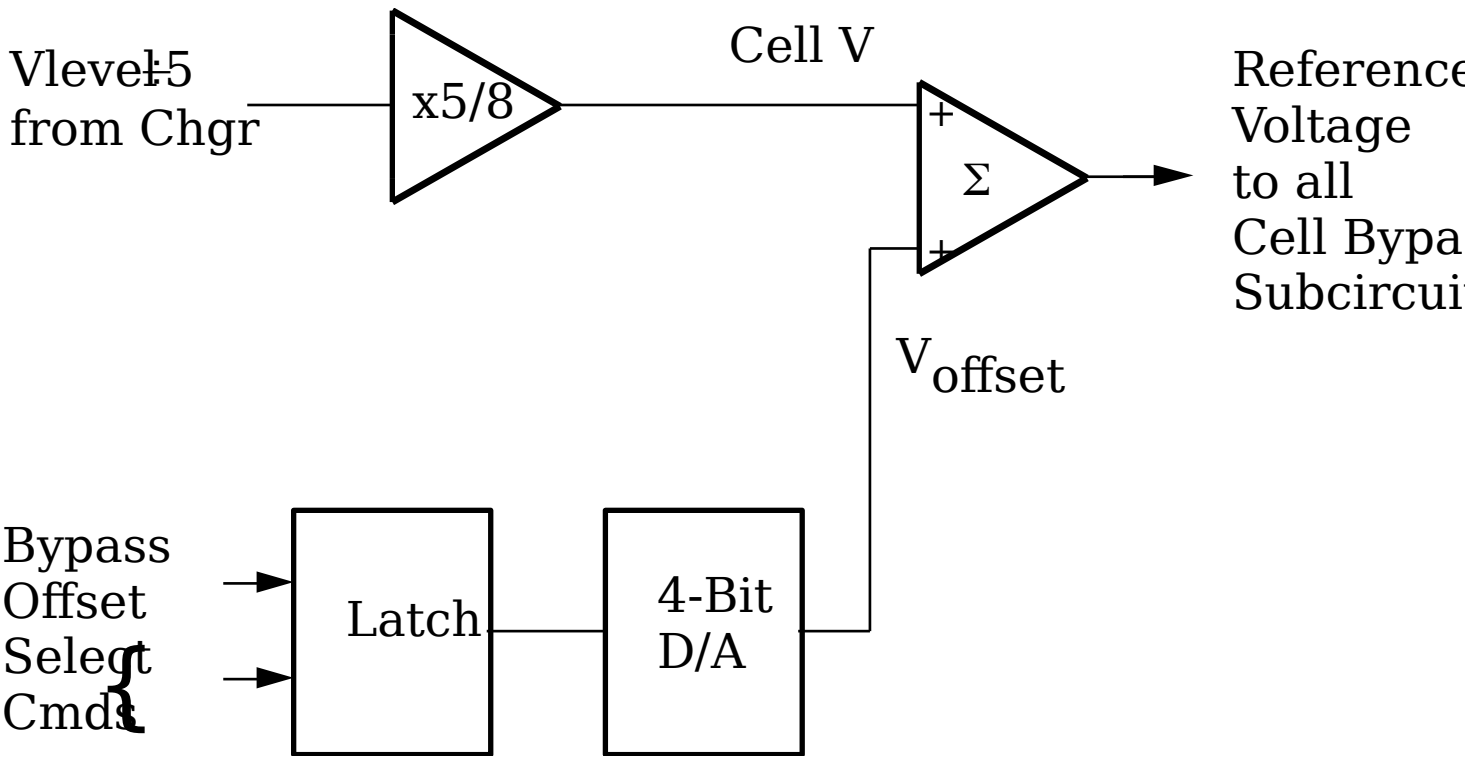
BCB Features

- Provides Battery Cell Overvoltage Protection and Balancing
- Bypasses of Up to 4Amps for Each Cell to Limit Cell Voltage; Each Cell Has a Dedicated Closed-Loop Bypass Circuit
- Cell Bypass Voltage Setpoints Automatically Controlled by PCU Battery Charger Voltage Control Limit/8
- Voltage Offsets of 0.0v, 0.1v, 0.2v, 0.3V Can Be Commanded
- Designed to Maintain Battery Charge and Discharge Current Path In the Event of an Open Circuit Battery Cell
- Power Diode Provides Discharge Current Path of 25Amps
- Provides Telemetry of All Cell Voltages and Bypass Currents

FAME Cell Bypass Detail

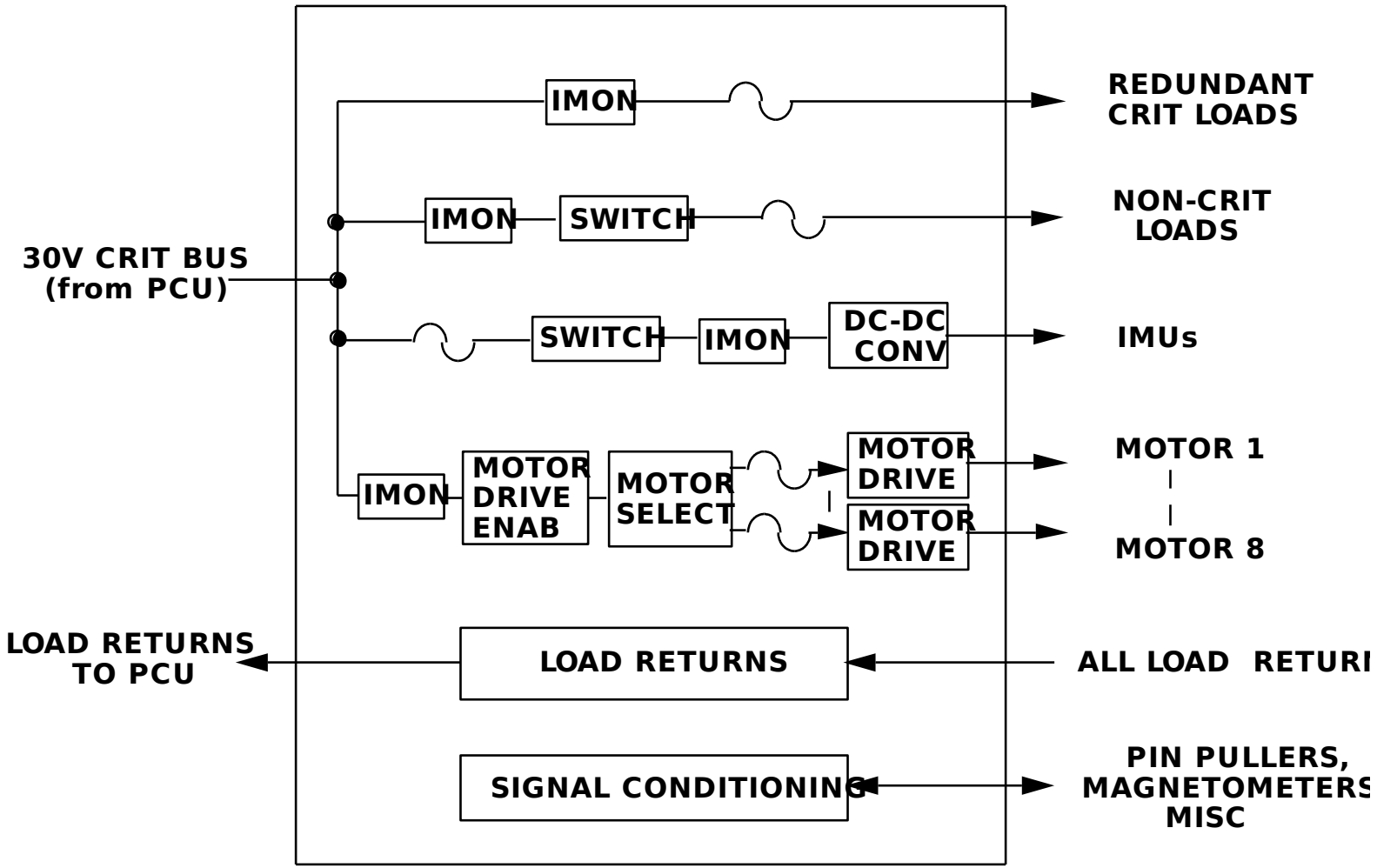


FAME Cell Bypass Reference Circuit



Power Distribution Unit

FAME EPS
Power Distribution Unit



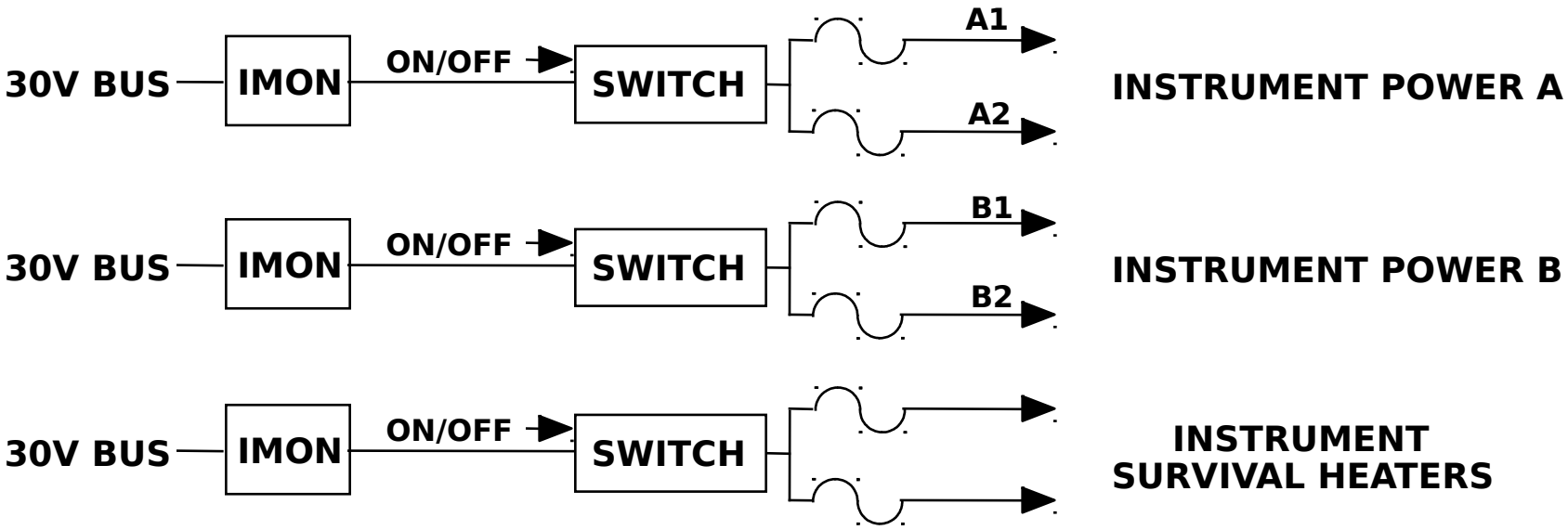
PDU Features

- **Provides Fused, Unswitched Power to All Redundant Critical Loads**
- **Provides Fused, Switched Power to All Non-Critical Loads**
- **Provides Fused, Switched, Regulated Power to Both IMUs**
- **Provides Motor Drive Signals and Fused Power to All Eight Motors**
- **Monitors Housekeeping Parameters Such As Currents, Voltages and Status**

FAME EPS Load List

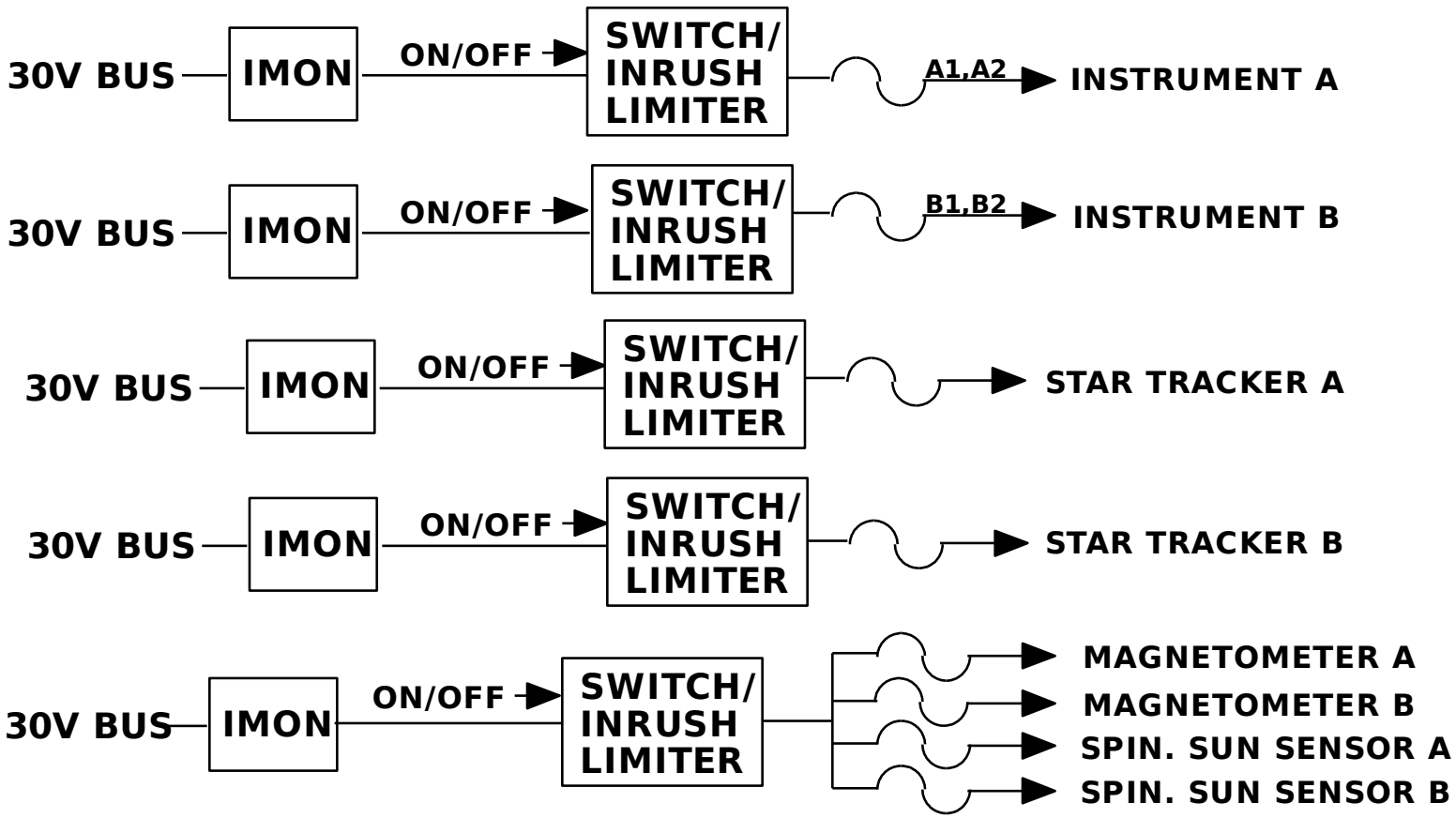
- 2 Instrument Feeds
- 2 Flight Spacecraft Controller Feeds
- 2 Remote Interface Unit Feeds
- 2 Receivers
- 2 Transmitters
- 2 Star Trackers
- 8 Motors
- 13 Heater Circuits
- 2 Inertial Mearsurement Units
- 2 Magnetometers
- 2 Spinning Sun Sensors

FAME EPS Instrument Interface

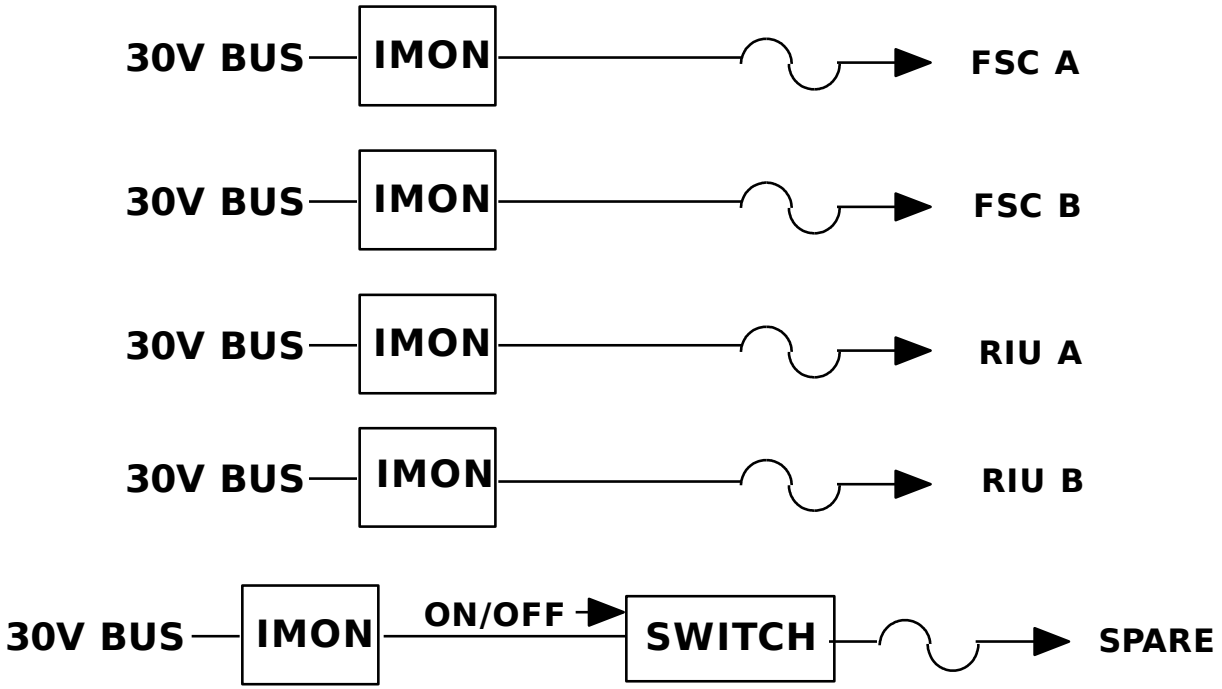


- Two Power Feeds to the Instrument Electronics
  - Both Power Inputs Can Be Active at One Time
- Separate Power Feed to the Instrument Survival Heaters
- Each Power Feed Shall Have
  - Current Monitor
  - On/Off Switches With Inrush Limiting
  - In-Line Fuses

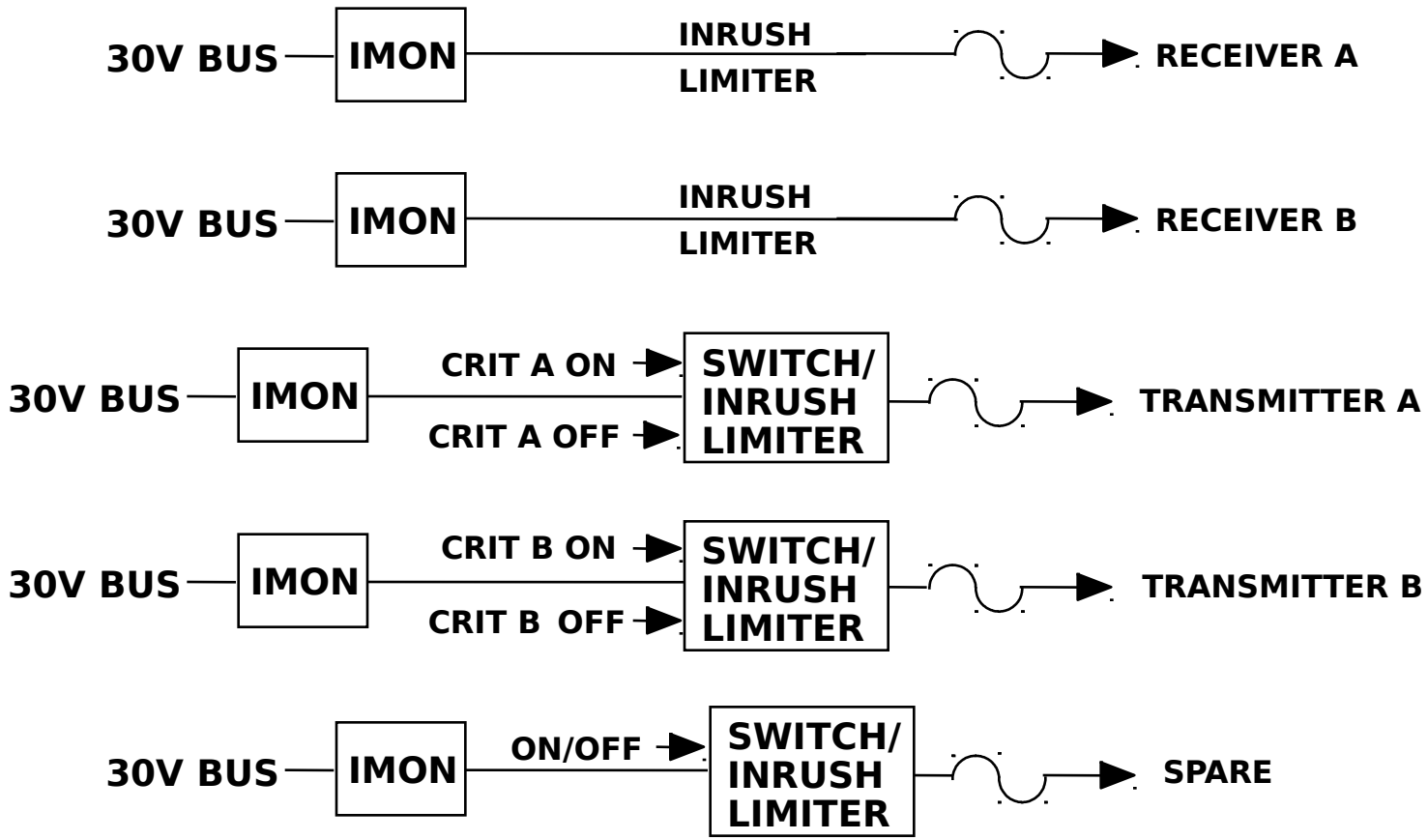
FAME Instrument Power Distribution Block Diagram



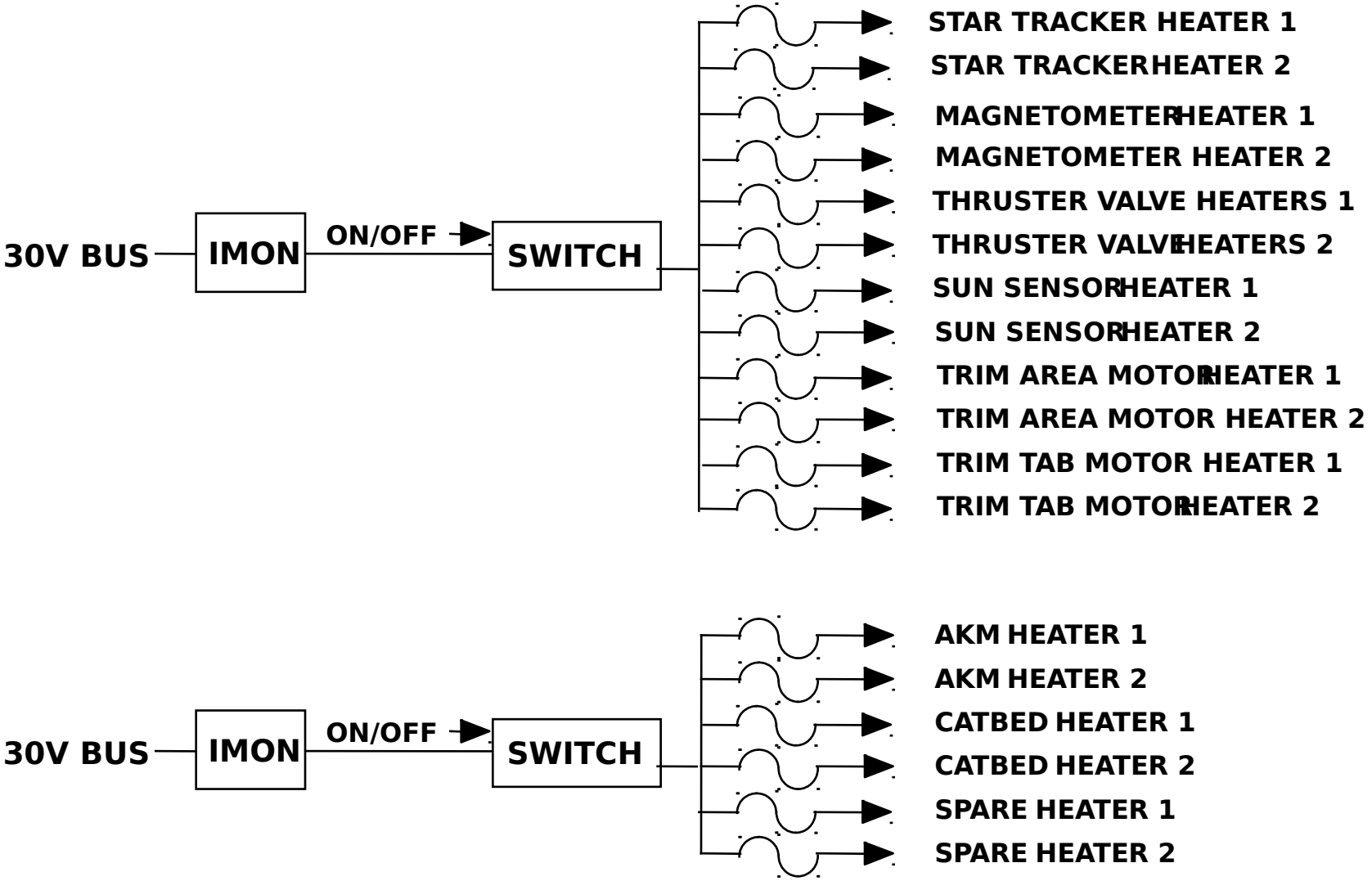
FAME CT&DH Power Distribution Block Diagram



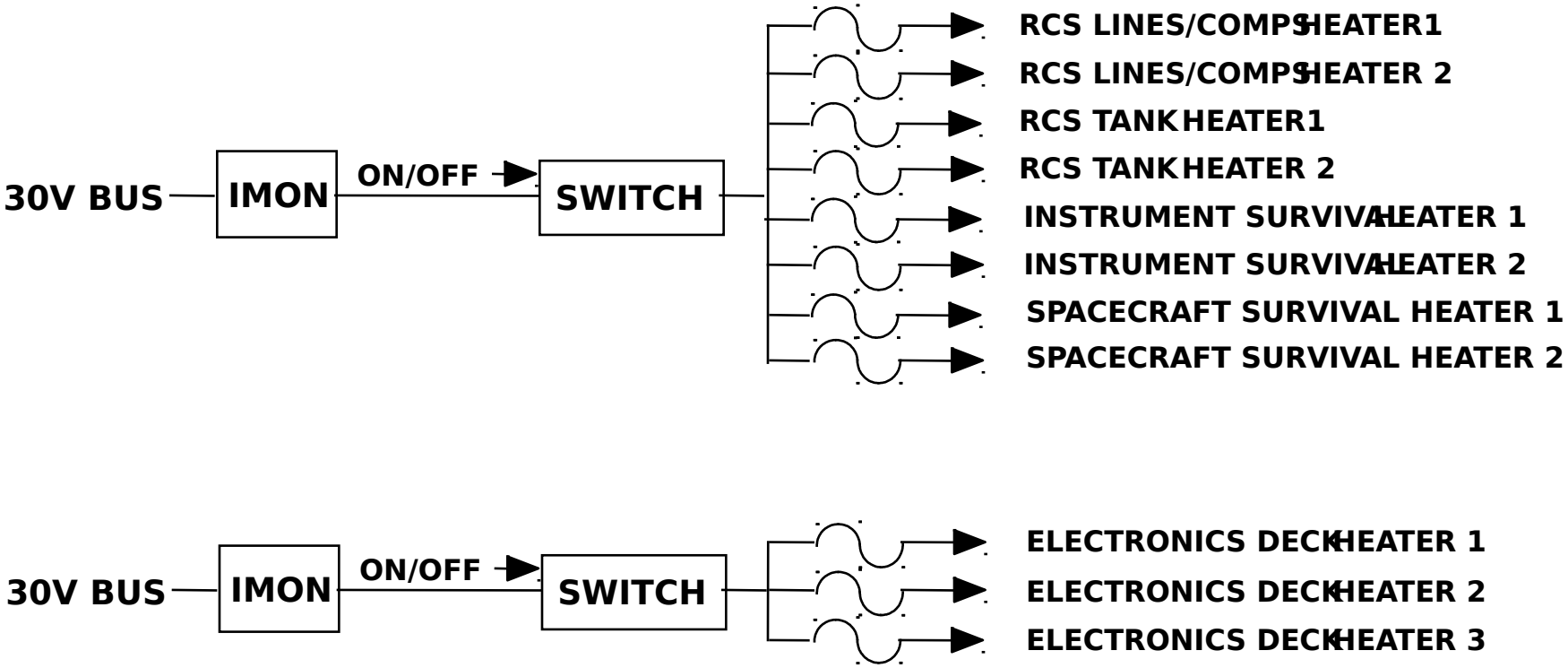
RF Power Distribution Block Diagram



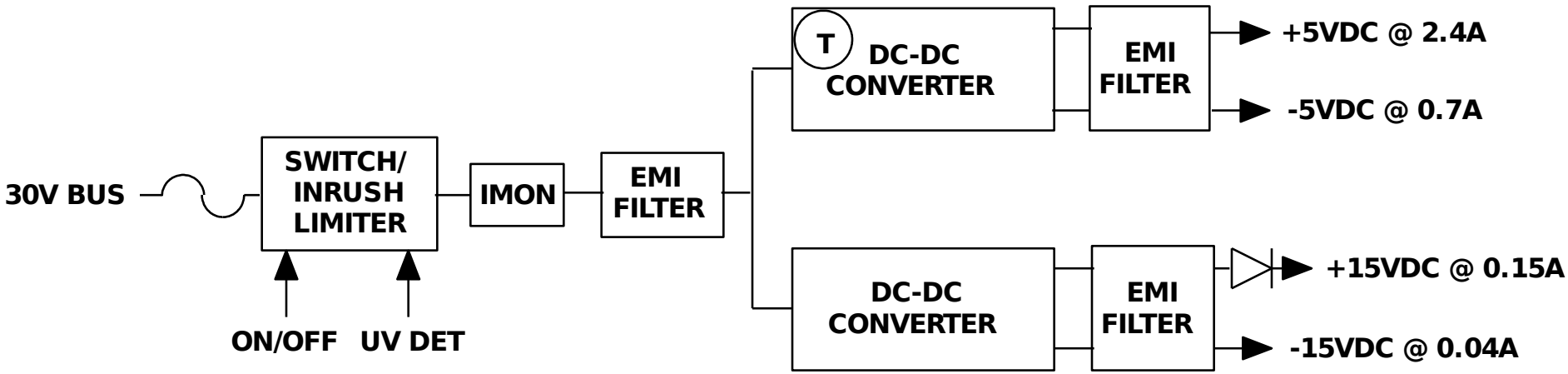
FAME Heater Power Distribution Circuit (1 of 2)

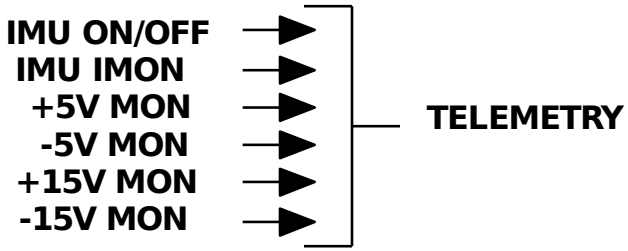


FAME Heater Power Distribution Circuit (2 of 2)

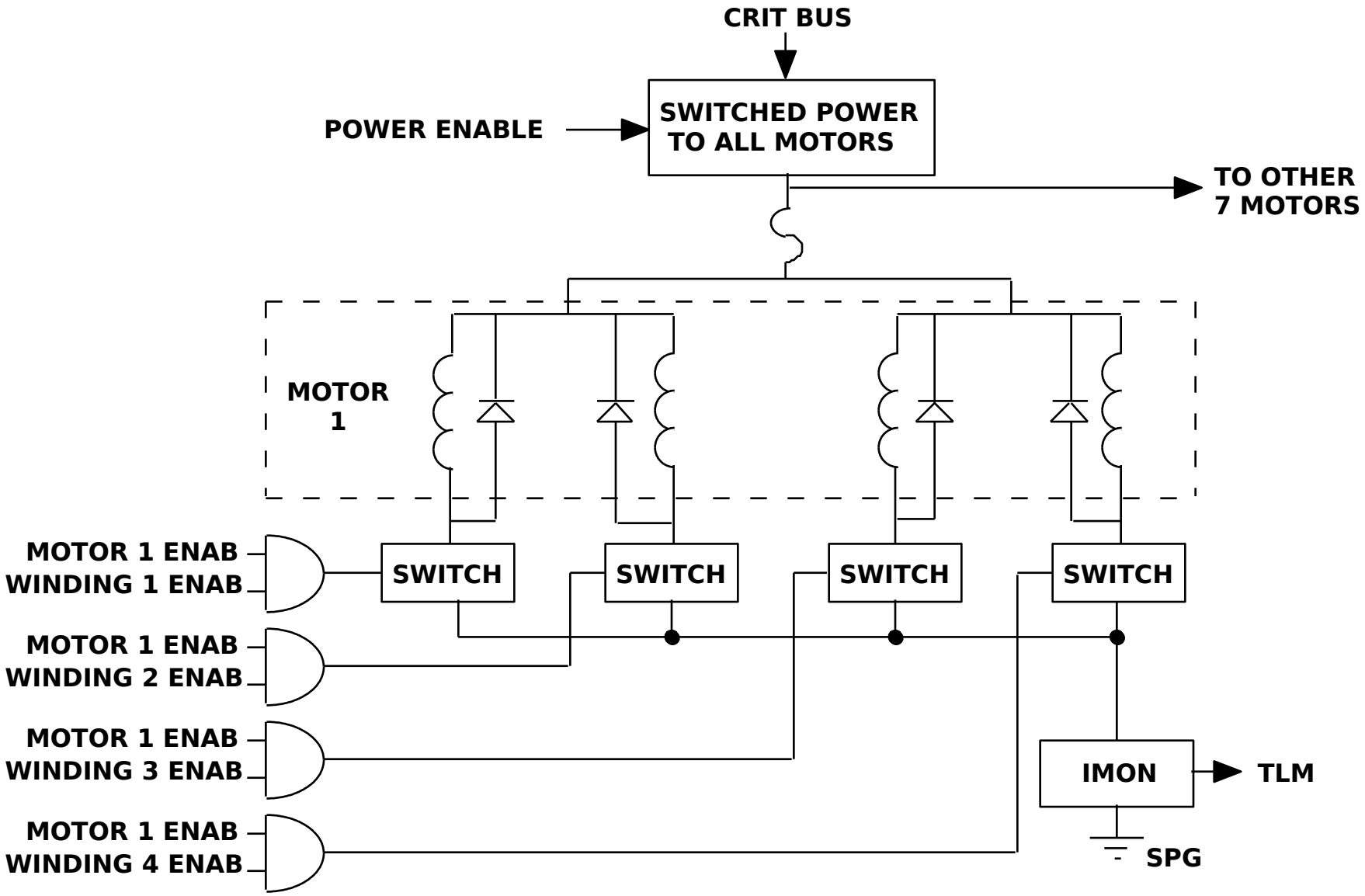


IMU Power Supply Block Diagram





PDU Motor Driver Circuit



Ordnance Control Element

Requirement Sources

- **Eastern and Western Range 127-1 (31 December 1999)**
  - **Section 3.3 General Design Policy**
    - **Failure/Hazard Criteria**
  - **Section 3.5 Operations Safety Console**
    - **SRM Safe and Arm Status**
  - **Section 3.13 Ordnance Systems**
    - **Design Requirements**
    - **RF Survivability Shall Meet Requirements in MIL-STD-1576**
  - **Section 6.13 Ordnance Operations**
    - **Transportation, Storage, Operations, Procedures**
- **MIL-STD-1576 – Electroexplosive Subsystem Safety Requirements and Test Methods for Space Systems**
  - **Paragraph 6.10 EMC Verification**

127-1 Range Safety Requirements (1 of 2)

- If a System Failure May Lead to a Catastrophic Hazard, the System Shall Have Three Inhibits (Dual Fault Tolerant)
- Hazard Classification
  - Solid Rocket Motor/Marmon Clamp Are Category “A”
  - All Other Ordnance Devices Are Category “B”
- Category A Motor Ignition Circuits Shall Include Safe and Arm Device
- Non-Explosive Initiators (NEIs) Shall Be Classified As Category A or B
  - FAME Use Is Category B
- EEDs (Electro-Explosive Devices)
  - One Amp/One Watt No Fire Survivability Is Required
- FMECA Shall Be Performed in Accordance With MIL-STD-1543
  - Bent Pin Analysis Also Required

127-1 Range Safety Requirements (2 of 2)

- **Safety Devices**
  - **Switches, Relays and Safe/Arm Devices Shall Be Used to Provide Electrical and Mechanical Isolation Between Power Source and the EEDs**
- **Shielding**
  - **Firing Circuits Shall Be Completely Shielded**
- **Filtering**
  - **Non-Shielded Circuits Filtered to Prevent RF Entry Into Shielded Portion of System**
- **Checkout Circuitry Shall Be Provided to Test and Monitor Critical Circuits**
- **Limit Induced EMC Power to 20 dB Below the Maximum DC No-Fire Power of the EED**

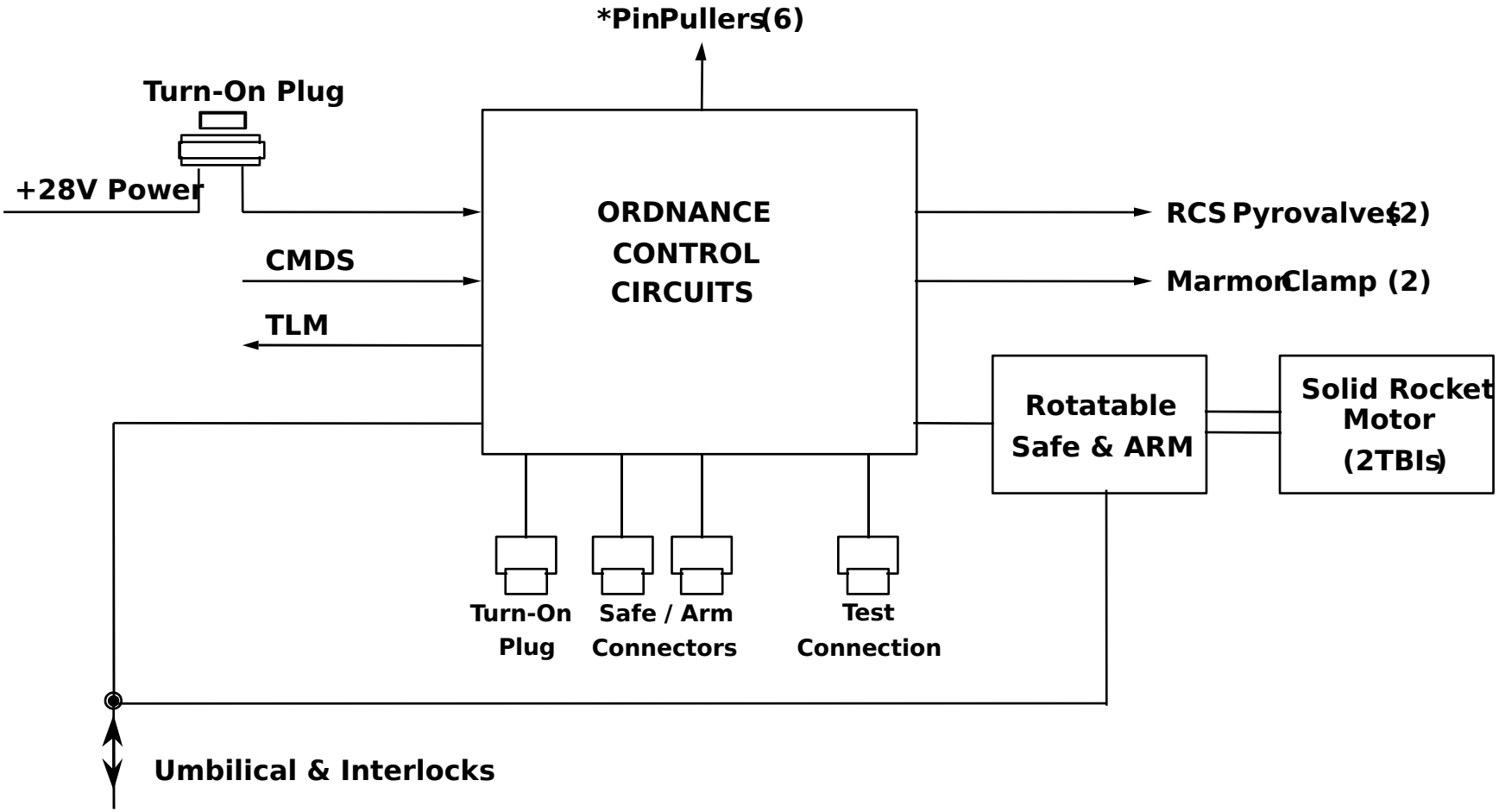
Operational Requirements

- **Provide Control and Firing Circuits to Safely Operate All Ordnance Devices and Non-Explosive Mechanisms**
- **Provide Switching and Control Logic for the Following Functions:**
  - **RCS Pyro Valve Activation**
  - **Solid Rocket Motor Ignition**
  - **Spacecraft/Interstage Separation**
  - **Trim Tab Release**
- **Provide Monitor and Control Functions to CT&DH, GSE & ELSE**
- **Provide Interface For Payload/Booster Separation**
- **Meet Range Safety Requirements for Ordnance (127-1)**

Key Safety Features

- **Turn-On Connector**
  - **Provides Ability to Remove Power From Ordnance Circuits Independent From Other Subsystems**
- **OCS Is Dual Fault Tolerant to Inadvertent Activation of Any Device**
  - **Three Inhibits, Two Monitored**
  - **Firing Requires Two Command Sequence**
  - **Electrical and Mechanical Safe/Arm Devices**
- **Personal Safety**
  - **Trained Personnel**
  - **Ordnance GSE Is Current Limited to Prevent Inadvertent Activation While Testing**
  - **All Operations Performed Per Approved Procedures**

Ordnance Control Subsystem Interfaces



* Note: Pin Pullers Are Non-Explosive Devices

Interface Definitions (1 of 2)

- Structure Interfaces
  - Access to Safe/Arm Connectors on Exterior of Spacecraft
  - Separable Connectors to Interstage
    - Firing Circuit Outputs to SRM
  - Ordnance Devices
  - Pin-Pullers
- Command and Telemetry Interfaces
  - CMDs (25)
    - Discrete CMDs for Ordnance Enabling Arming and Firing
  - TLM
    - Bi-Level Data Points (12)
- Power Interface
  - 28 Volt Bus

Interface Definitions (2 of 2)

- ELSE
  - SRM Safe and Arm Device Driven Through Umbilical
    - SRM Armed Just Prior to Launch
  - SRM Safe/Arm Status Indicator
  - Ordnance Inhibit Status Indicators
  - Inhibit Reset Ability
- Test Connector
  - Ordnance Inhibit Status Indicators
  - Inhibit Reset Ability

Ordnance Device Distribution and Type

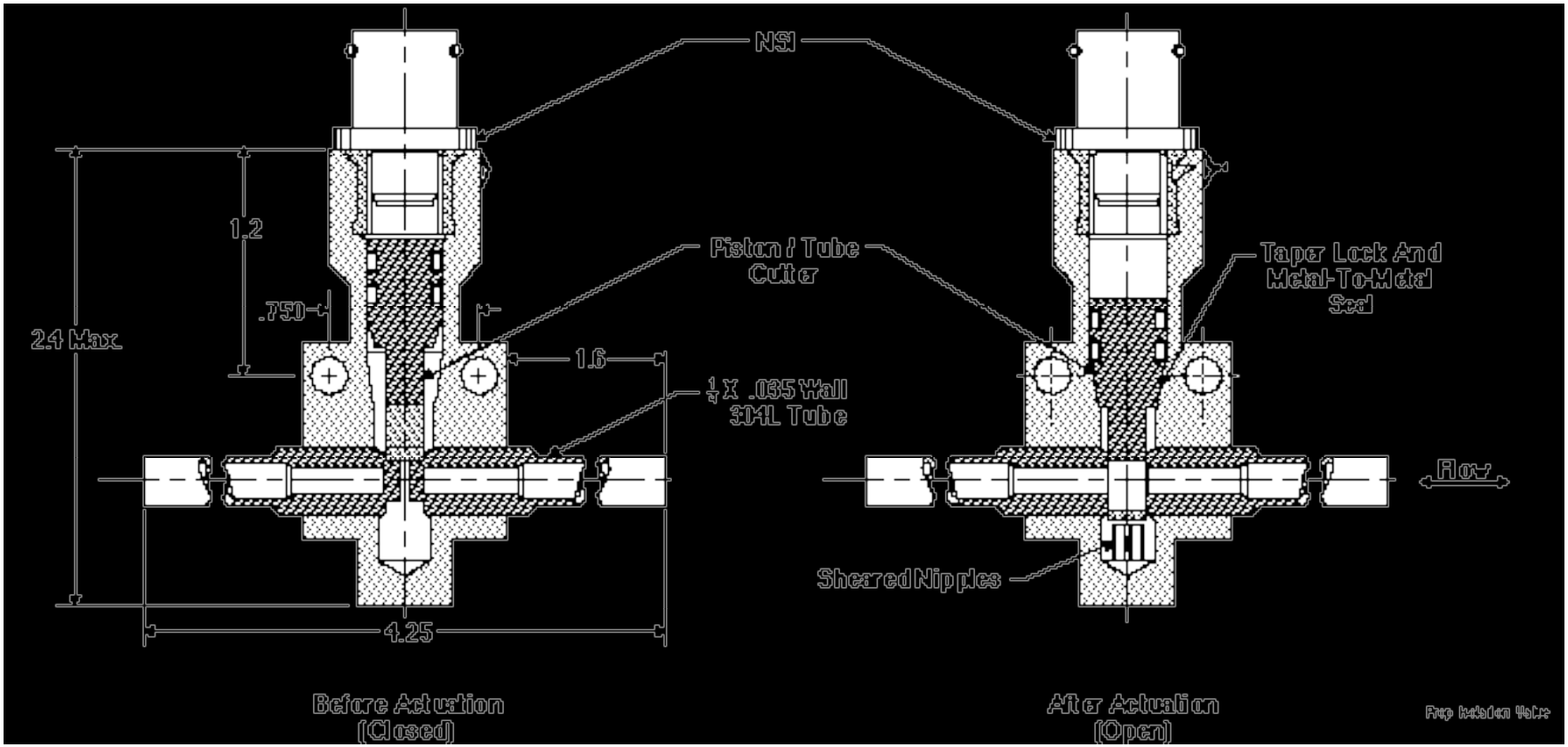
- **Electro-Explosive Devices (EEDs):**

Usage	Device Type	Quantity
Marmon Clamp Separators (2)	PC-72-003	2
RCS Pyro Valves (2)	NSI	2
Solid Motor Ignition (2)	TBI	2
Spares (2)		
TOTAL EEDs		6

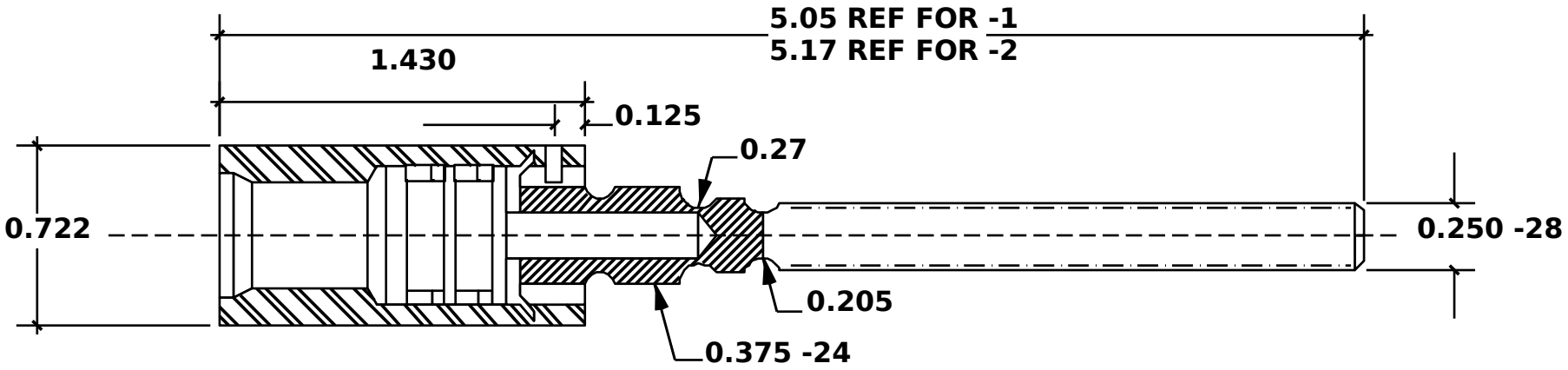
- **Pin Pullers (NEIs):**

Usage	Device Type	Quantity
Trim Tab Release (6)	Nitinol Actuator	12
Total Actuators		12

Pyro Valve Detail



Clamp Separator



Ordnance Event Sequence

Event	Commands to Complete	Number of Devices Functioned	Comments
Launch Vehicle			
Spacecraft Release	1	2	Initiated by Launch Vehicle
Total LV Ordnance Events	1	2	
Space Vehicle			
RCS (Pyro) Valve Activation	1	2	
Solid Motor Ignition	1	2	
Trim Tab Release	3	6	6 Pin-Pullers 2 Actuators Per Unit
Spacecraft/Interstage Separation	1	2	Marmon Clamp
Total Space Vehicle Ordnance Events	4	12	

Ordnance Control Circuits Description (1 of 2)

- Located in PCU
  - Three Circuit Card Assemblies
- Contains Inhibit and Firing Relays
- Contains Monitor and Control Circuitry
- Provides Command and Status Interfaces to CT&DH System
- Provides Status Information and Inhibit Reset Ability Through Ground Test Connector and Umbilical
- Provides Outputs to Pyro Devices
- Provides Outputs to Pin-Puller Devices

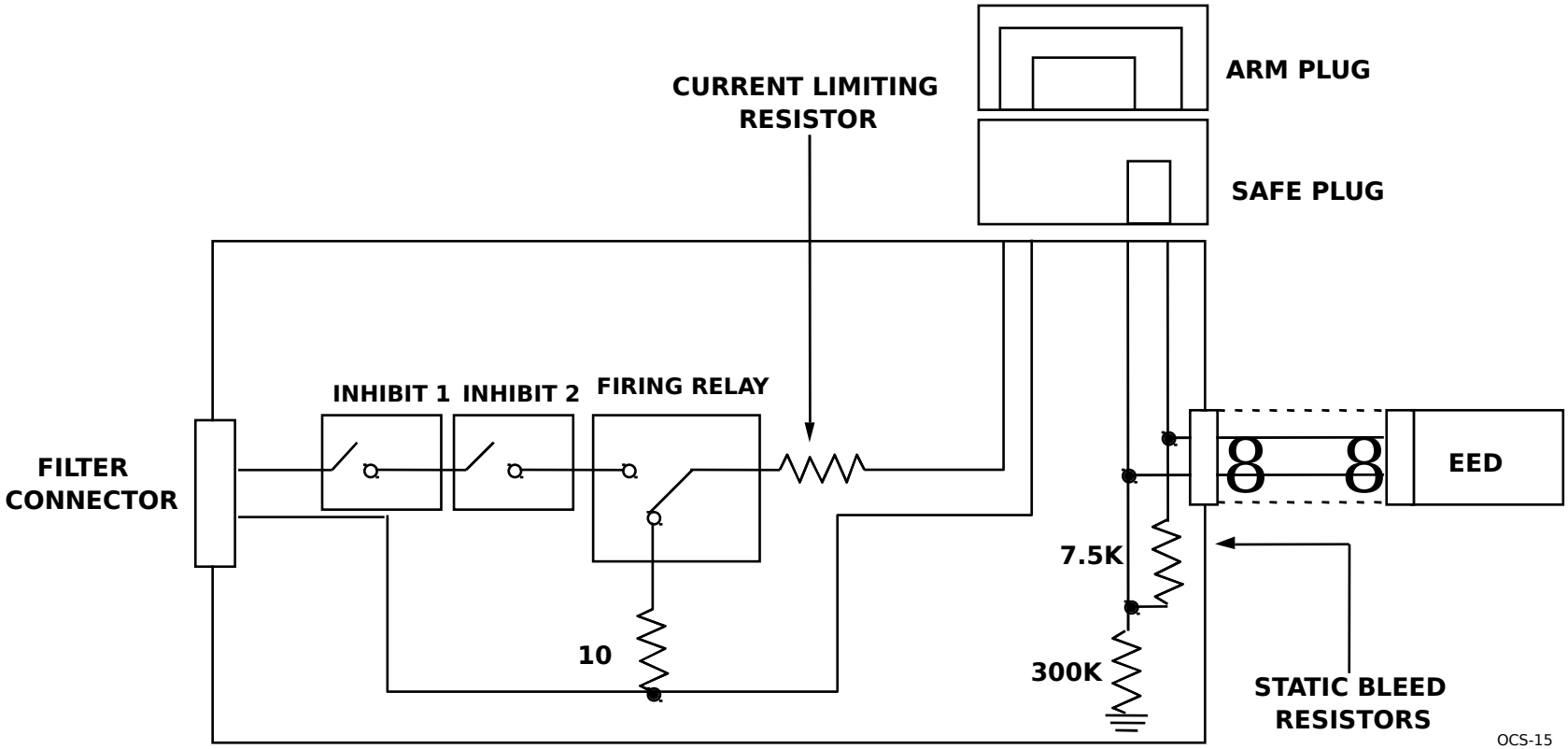
Ordnance Control Circuits Description (2 of 2)

- **Two Inhibit Relays Interlocked Through Space Vehicle/Launch Vehicle (SV/LV) Interface Connector**
  - **Inhibit Relays Closed by Ground Command**
  - **Interlock Prevents Arming Before SV/LV Separation**
- **EED Firing Relays**
  - **Six 2PDT Spring Return Relays for Firing Pyros**
- **Six Pin-Puller Relays**
  - **2 PDT Latching Relays for Pin-Puller Actuator**
- **Ground Test Connector**
  - **Monitors Inhibit Relay Positions Without System Power**
  - **Returns Inhibits to Safe Positions**
- **Umbilical Resets and Status**
  - **Ability to Monitor and Reset Inhibits With EAGE**

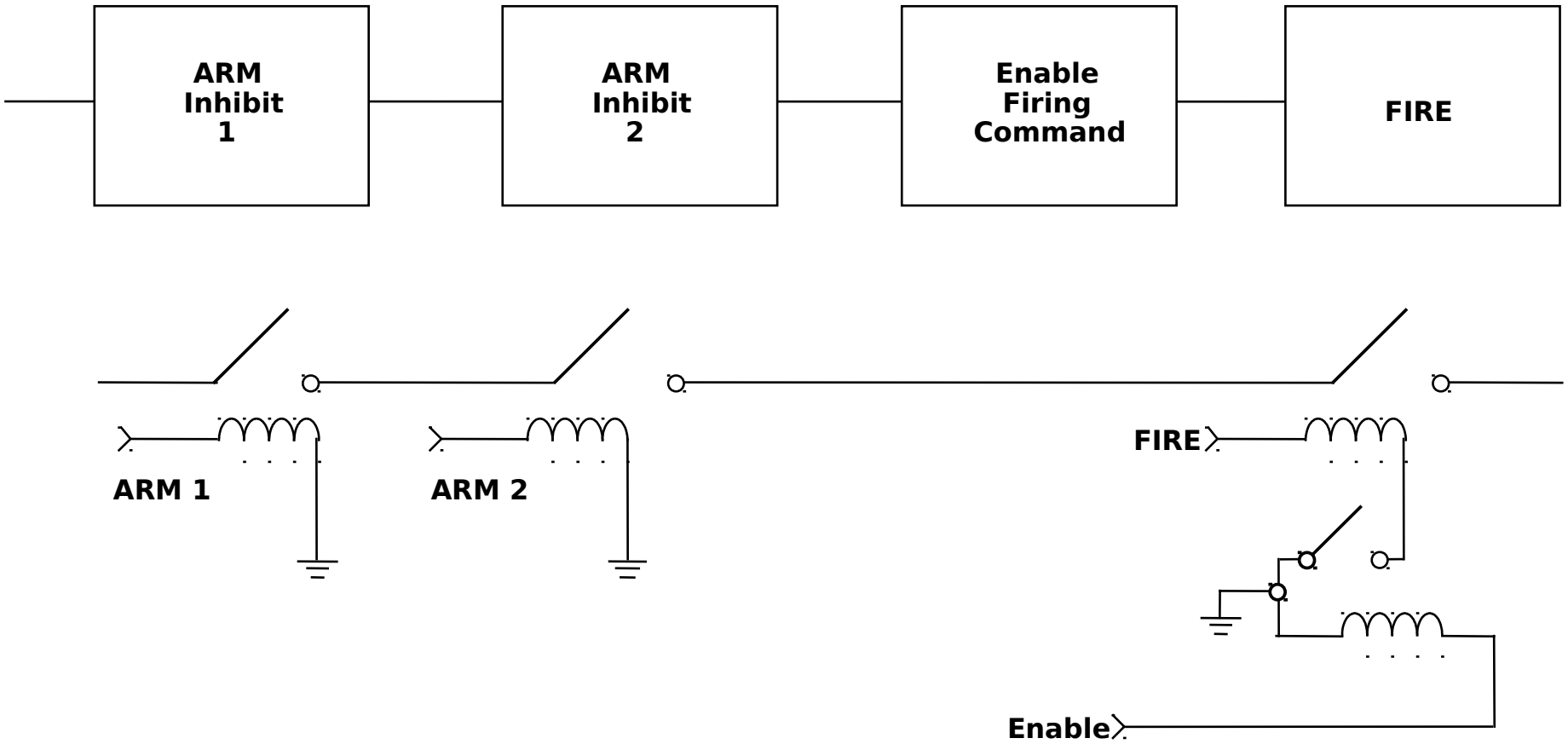
Ordnance Control Design Features

- Zero Standby Power
- Inhibit Interlocks Prevent Arming Prior to SV Separation
- All Ordnance and Release Events Requires a Two Command Sequence
  - 1. Enable
  - 2. Fire
- Inhibits Are Resettable Via Two Paths
  - Test Connector Using GSE
  - Umbilical Using EAGE
- EED Firing
  - Fusible Resistors Provide Uniform Current to Changing Electro Explosive Devices (EED) Resistance During Initiation
  - Static Bleed Resistors Reference All Firing Lines to Structure Ground (WSMC-127-1 RQMT)
- Pin-Puller Firing
  - Series Resistors Limit Current to Pin-Puller Actuators

Ordnance Control Design Overview

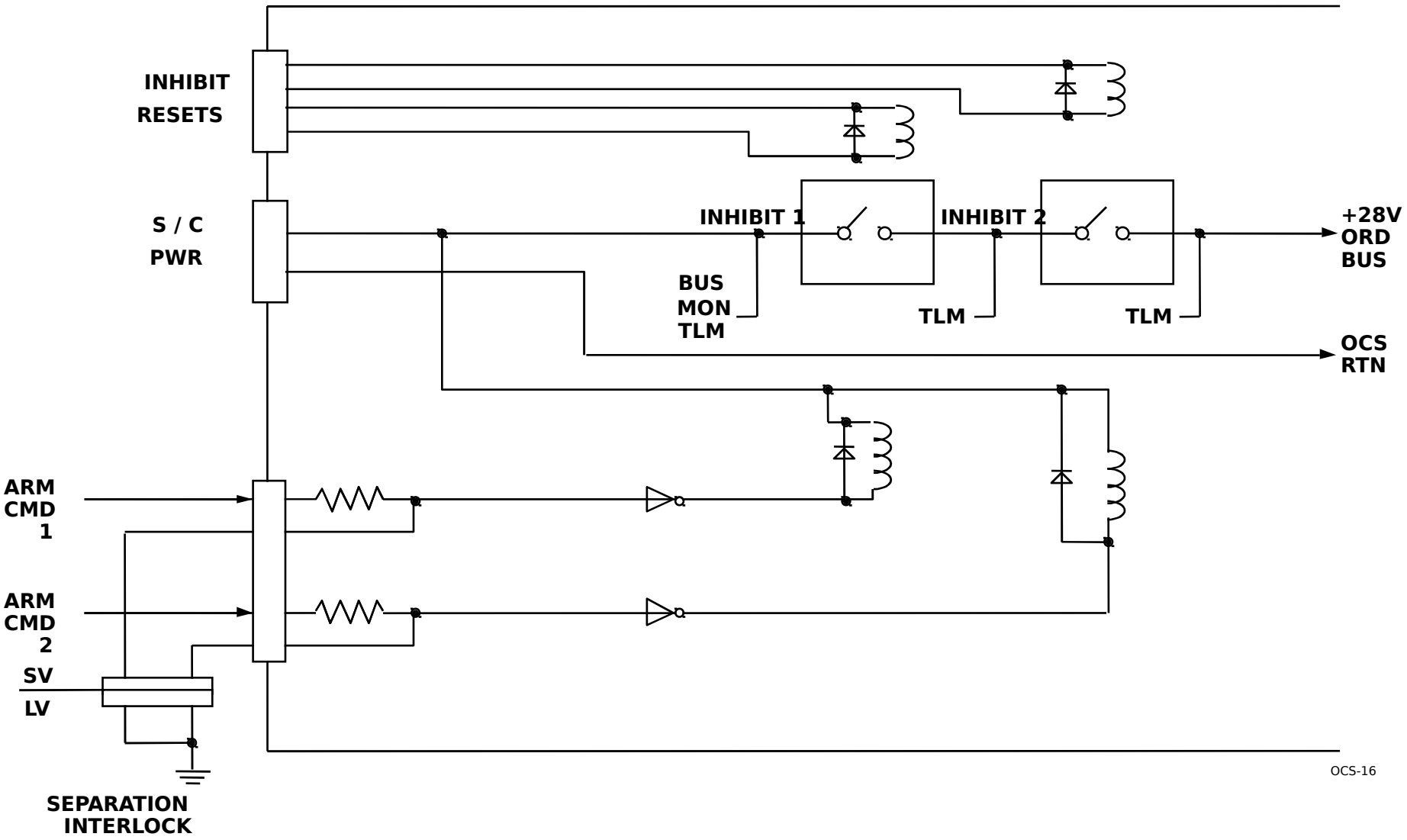


Arm and Enable Sequence

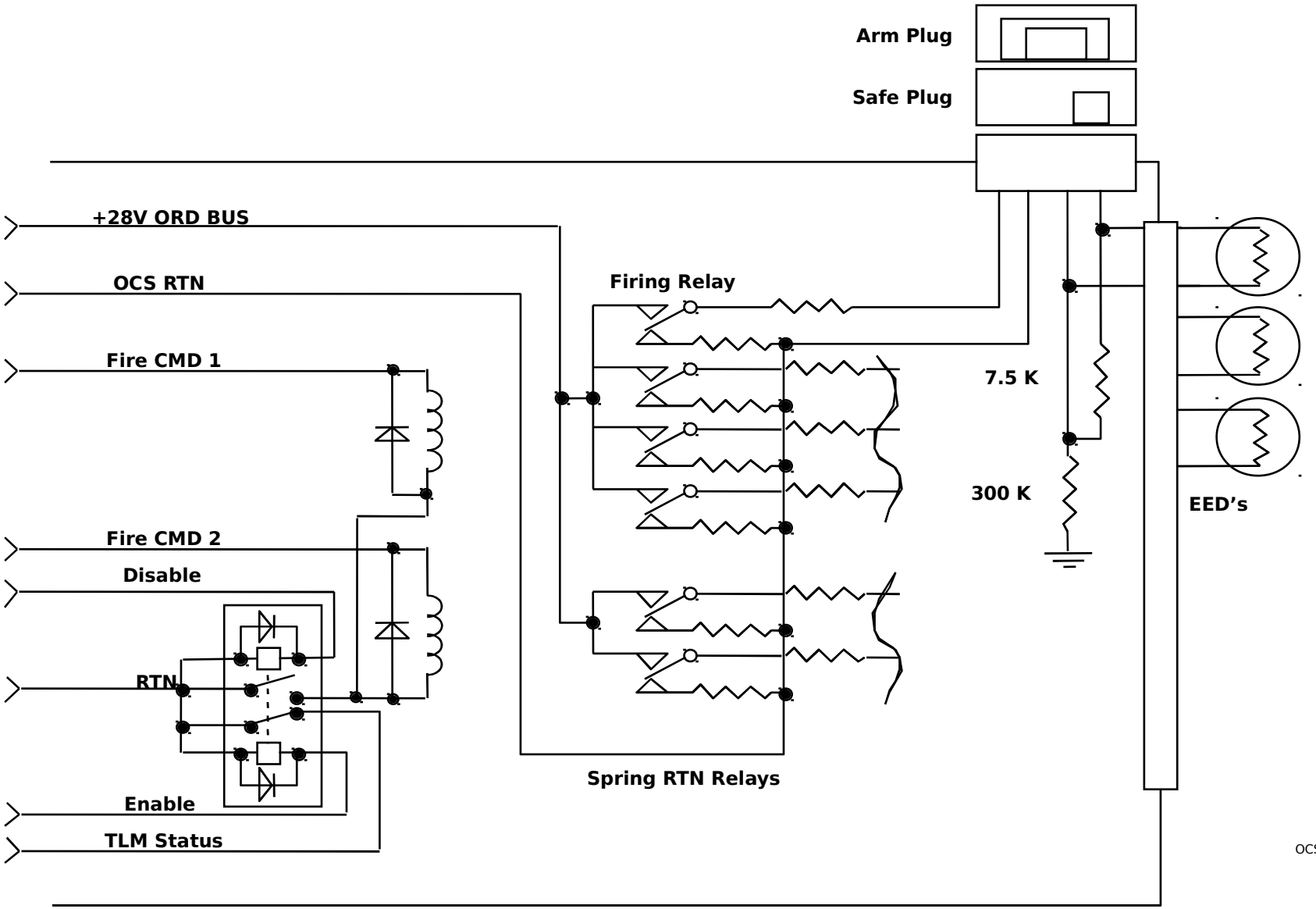


Note: Safe & Arm Plug Not Shown

Ordnance Control Circuits

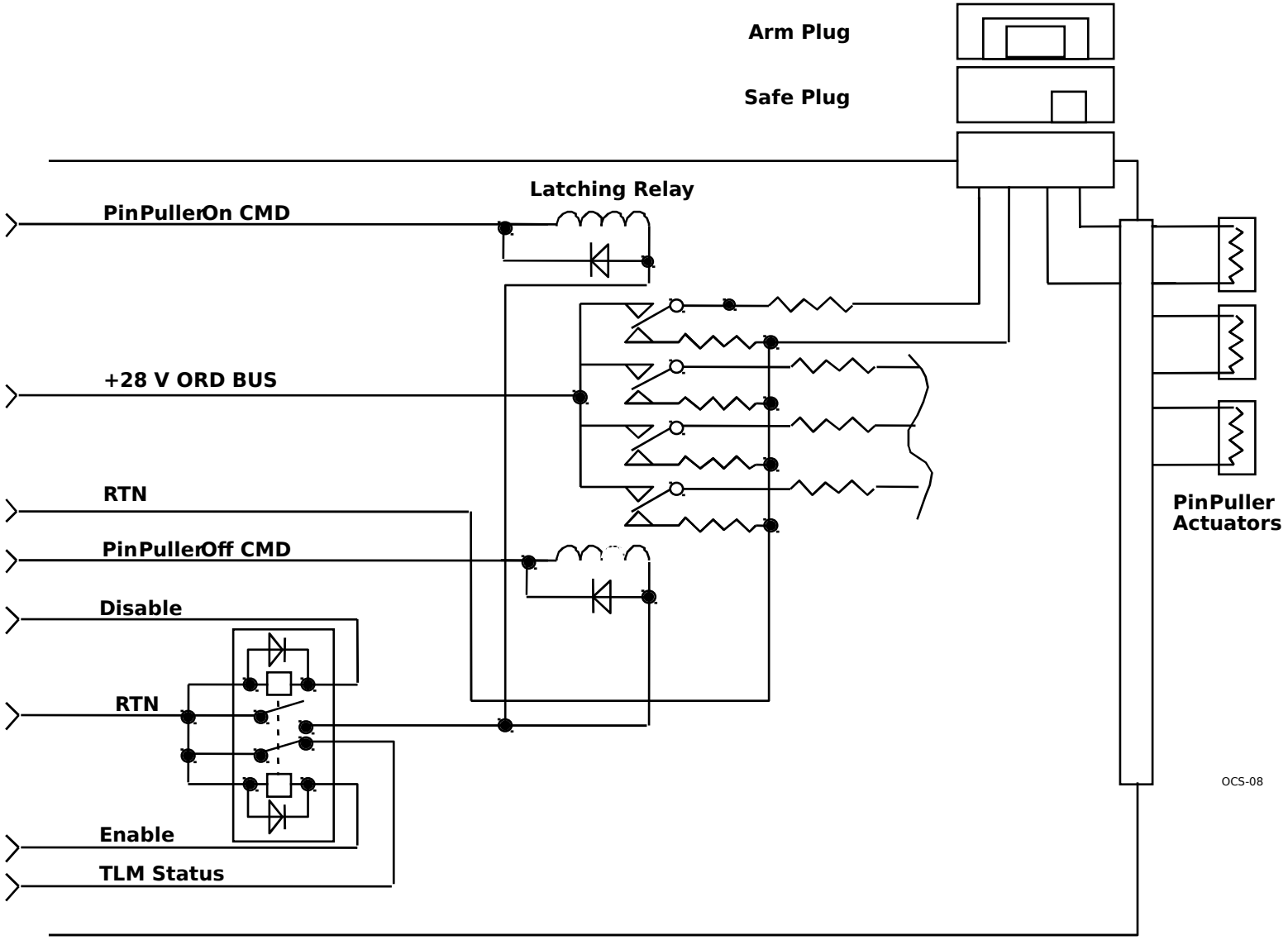


EED Firing Circuits

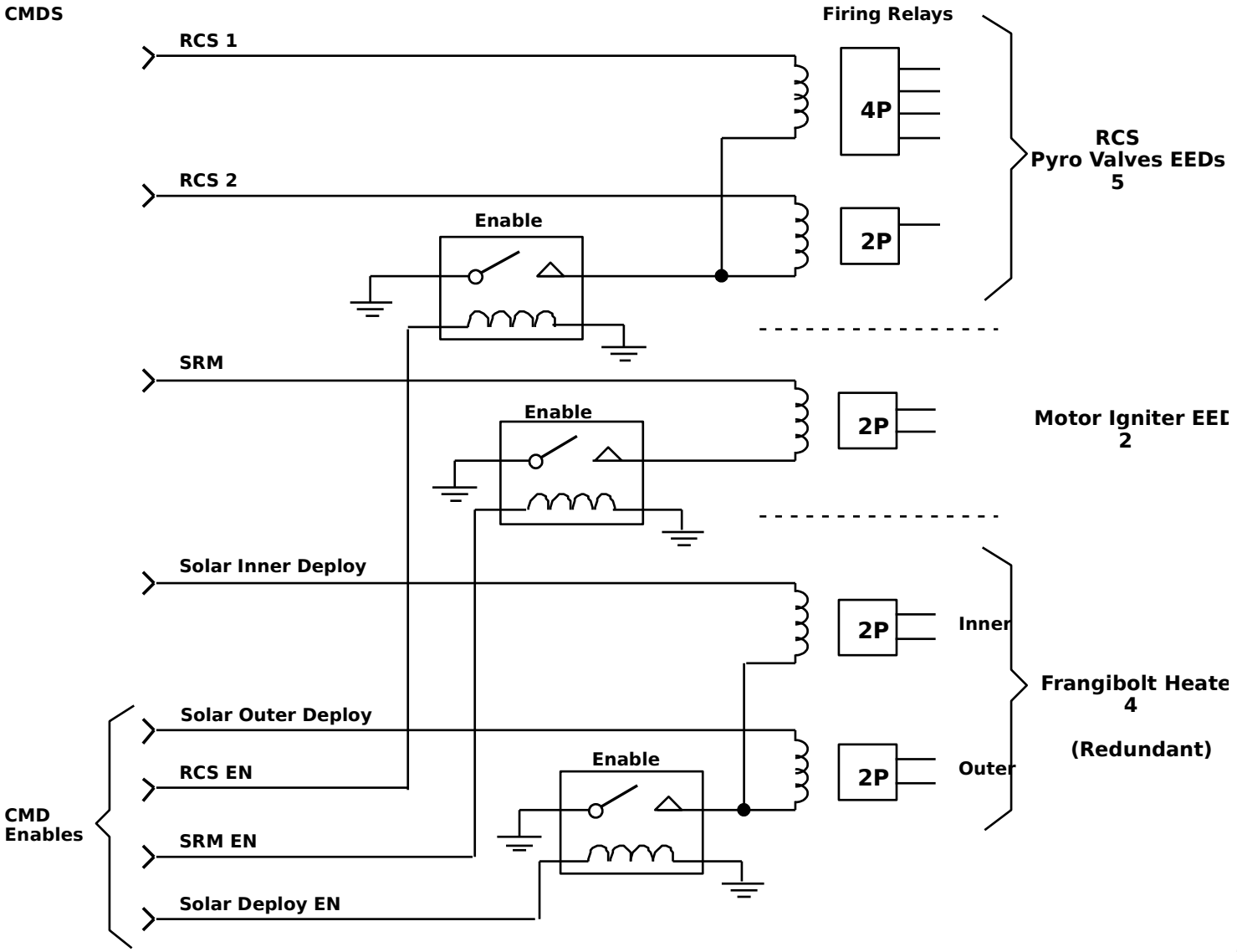


OCS-07

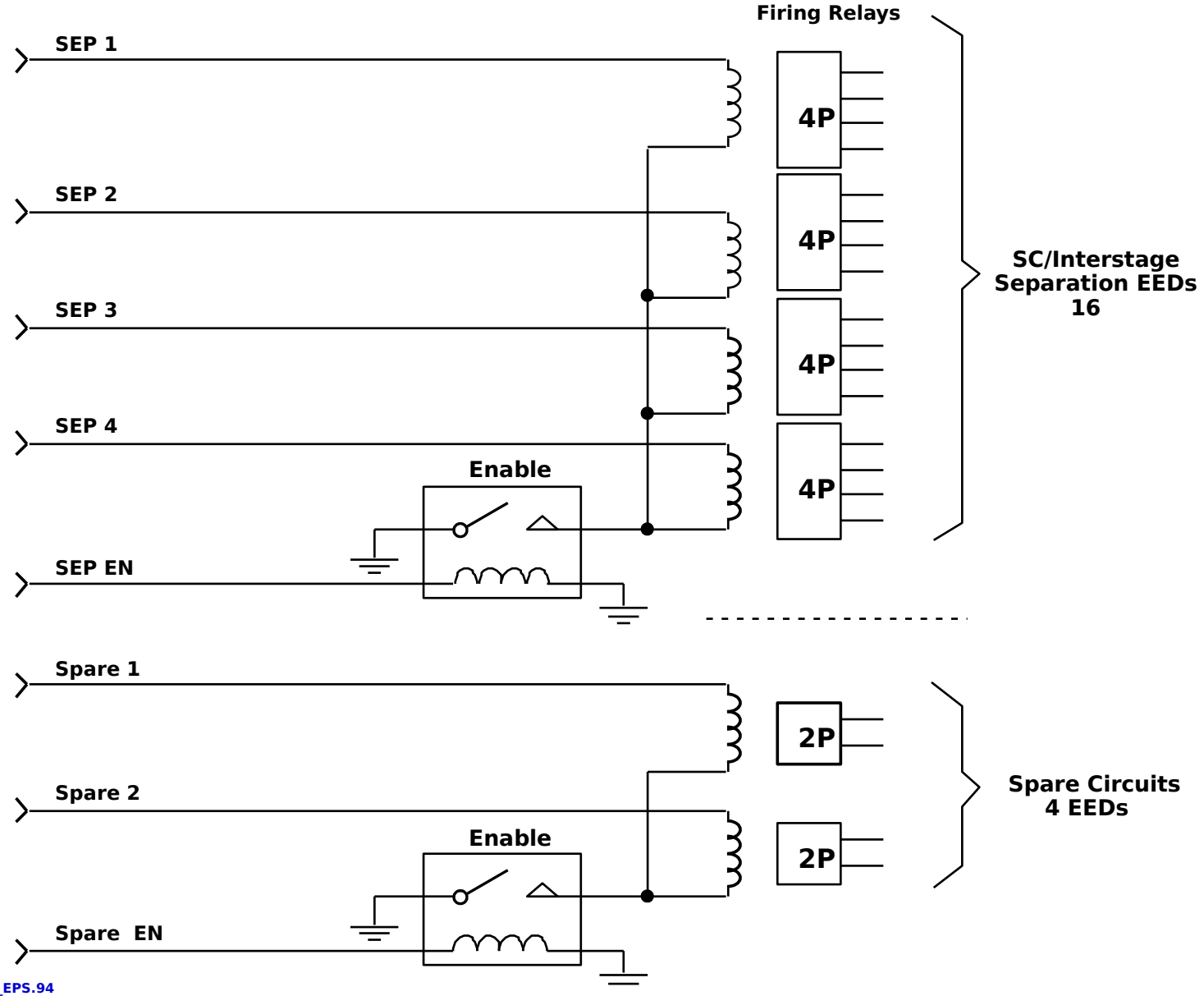
Pin-Puller Firing Circuits



Command Enables Diagram (1 of 2)



Command Enables Diagram (2 of 2)



EED Firing Current Margin

NSI "All Fire" Current: 3.5 Amps

- **Current Limiting Resistors Sized to Provide:**

Bus Voltage	EED Firing Current
34.0 Volts	6.07 Amps
28.0 Volts	5.00 Amps
22.0 Volts	3.92 Amps

- **Maximum Current Draw @ 34V Is 12.1 Amps Peak (413 W)**
  - **Occurs 3 Times**
- **Peak Current Delivered Until EEDs Fire (Approx. 2 ms)**
- **Total Energy Per Firing (Max) Is 413 W x 2ms – 0.83 W/S**

Pin-Puller Actuator Margins

Minimum Pin-Puller Current Required: 2.3A

- **Redundant Actuators Used**
  - **Actuator Resistance Is 1.2 ohm**

Bus Voltage	Actuator Current
34.0 Volts	3.6 Amps
28.0 Volts	3.0 Amps
22.0 Volts	2.3 Amps

- **Circuits Are Self Terminating**
- **Maximum Bus Current Draw @ 34 V Is 7.2 Amps**
  - **Occurs 6 Times for 1.5 Seconds (Max)**

Ordnance Control Operation

- **Orbital Insertion**
  - **Marmon Clamp Separators Fired By LV**
  - **Space Vehicle Is Released**
- **Fire RCS Values**

CMD	Action	
RCS Fire	Opens	PIEV1, PIEV2

- **Fire SRM**

CMD	Action
SRM Fire	Fires EEDs to Ignite SRM

- **Spacecraft/Interstage Separation**

CMD	Action
SEP	Releases Marmon Clamp

- **Release Trim Tabs**

CMD	Action
PP Fire	Fires Pin- Pullers

Ground Support Equipment

- Ground Ordnance Test Set (GROTS)
  - Interfaces With Test Connector on Spacecraft
  - Provides Ability to Monitor Inhibit Relay Positions Without System Power
  - Provides Ability to Return Inhibits to Safe Positions
- Bridgewire Resistance Test Set (BRETS)
  - Interfaces With EED or Safe and Arm (S/A) Receptacle
  - Measures Bridgewire Resistance
    - Current Limited to 10 mA
    - 0.001 0hm Resolution
- Spacecraft Ordnance Test Set (SCOTS)
  - Interfaces With S/A Receptacle
  - Power off/on Stray Voltage Measurements

Ordnance Safety (1 of 2)

Ordnance Control Subsystem Safety Design Features:

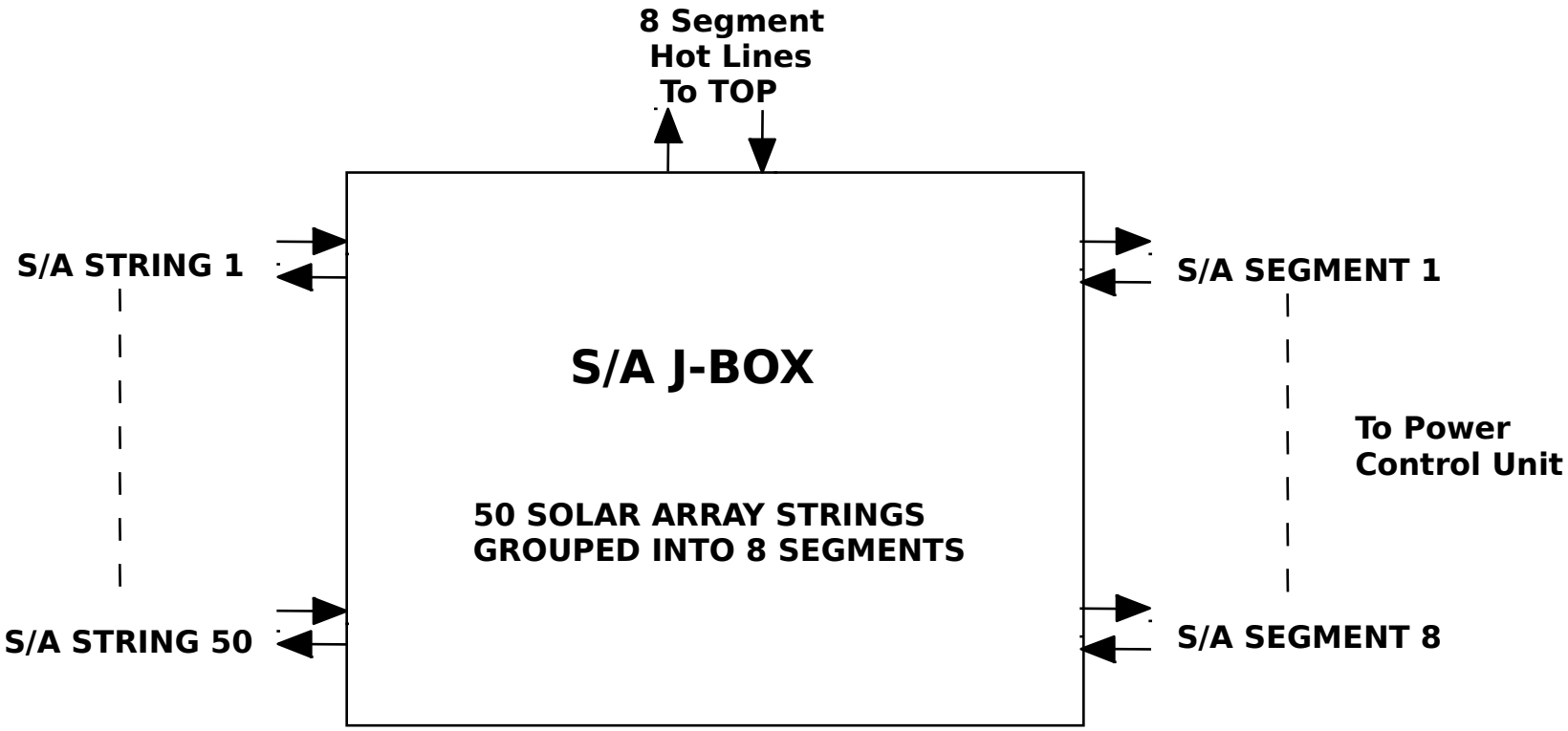
- **Power on Connector**
  - **Removes Power From Ordnance Independent of Other S/C Subsystems**
- **Filter Connectors**
  - **Prevents Unwanted Electromagnetic Energy From Entering the OCS System**
- **Inhibit Interlock**
  - **Prevents Pre-Separation Arming**
- **Ground Test Connector**
  - **Provides Ability to Return Inhibits and Enables to Safe Positions**
- **EAGE (Umbilical)**
  - **Monitors Status of Inhibits and Can Return Inhibits and Enables to Safe Positions**
  - **Drives Solid Rocket Motor (SRM) Safe/Arm Device**

Ordnance Safety (2 of 2)

- All Firing Circuits Pass Through Electrical Safe/Arm Connector
  - Safe Plug
    - Provides Positive Interruption of the Current Path From the OCB to the EEDs
    - Electrically Shorts the EEDs Across the Bridgewires
  - Static Bleed Resistors Drain Any Static Buildup to Structure
  - Safe/Arm Receptacle Provides Test Point Location for Bridgewire Resistance and Stray Voltage Tests
- SRM Ignition Circuits Interrupted by Rotatable Safe/Arm Device
  - "Out-of-Line" Mechanism Provides Additional Positive Interruption for the Explosive Train

Solar Array Junction Box

Solar Array Junction Box

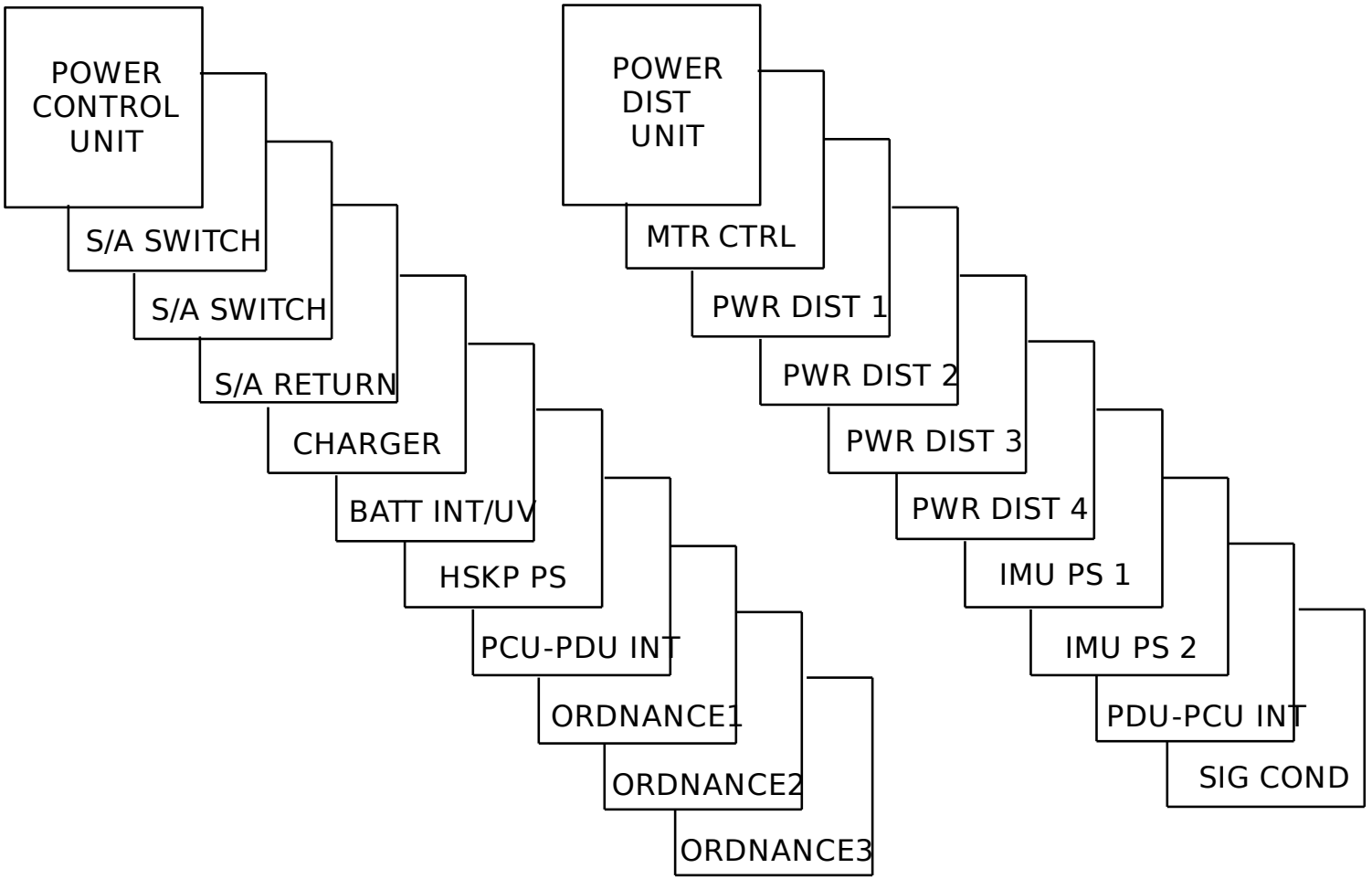


Box Mechanical Features

FAME EPOS
Size/Weight Estimates

Component	Length (inches)	Width (inches)	Height (inches)	Volume (cu. inches)	Weight (lbs)
PCU	15.50	8.75	6.67	905	21.17
PDU	12.25	8.75	6.67	715	17.52
BCB	5.70	8.75	9.00	449	8.16
S/A J-Box	7.06	6.00	2.25	96	1.68
Battery	4.32	7.46	6.00	193	18.41
Solar Array					10.8
Harness					22.36
Total					100.10

PCU & PDU Board Complement



United States Naval Observatory

LOCKHEED MARTIN

Command and Telemetry

FAME EPS Command List

- 12 Low Level Commands From the RIU
- 8 Low Level Commands From the FSC
- 48 High Level Commands From the RIU
- 5 High Level Critical Command From the FSC

FAME EPS Telemetry List

- **83 Active Analog Signals**
- **27 Passive Analog Signals**
- **42 Bi-Level Discrete Signals**

Harness

Connector Types

- **Rectangular Connectors**
  - **Miniature D, Crimp**
  - **MIL-C-24308**
- **Circular Connectors**
  - **MIL-C-38999, Series I Through IV**

Harness Wire

- **Wire Derating**
  - **Wire Current Carrying Capacity Shall Be Derated Per MIL-W-5088L**
- **Wire Type**
  - **Single Wire**
    - **MIL-W-22759/87, 90**
    - **19 Strands, Nickel Plated Copper (NPC)**
    - **PTFE/Polymide Insulation, Tufflite 2000**
  - **Twisted Pairs, Twisted Triplets**
    - **Components of MIL-W-22759/87, 90**
  - **Twisted Shielded Pairs**
    - **Components of MIL-W-22759/87, 90**
    - **Shield, NPC 85% Minimum Coverage**
    - **Outer Jacket, Polymide/FEP**
  - **Coax**
    - **Semi-Rigid Cable Type M17/1330-RG402**
  - **TWINAX Cable, 1553 Bus**
    - **MIL-C-17FM17/M6**

Assembly & Mechanical Design

Quality Assurance Efforts

Critical Bus Fault Mitigation

- All Critical Bus Harness Wires Shall Be Double Insulated
- All CCAs/Electrical Parts Shall Be Conformal Coated
- Heat Sinks Shall Be Hard Anodized and Conformal Coated
- Wires From I/O Connectors Shall Be Insulated, Tied in Bundles for Stress Relief, and Strain Relieved at the PWB Surface to Remove Stress From Wire to Solder Joint Junction
- Sharp Edges Near Connectors Shall Be Insulated and/or Staked
- Housing Shall Be Hard Anodized
- Inspections Shall Be Performed on All PWBs, Heatsinks, CCAs and Housings; All Assemblies Shall be Vacuumed to Remove Any Loose/Stray Materials
- NRL QC Personnel Shall Witness All Box Assembly Operations and Shall Verify That No Loose Materials Are Present Inside Any EPS Box

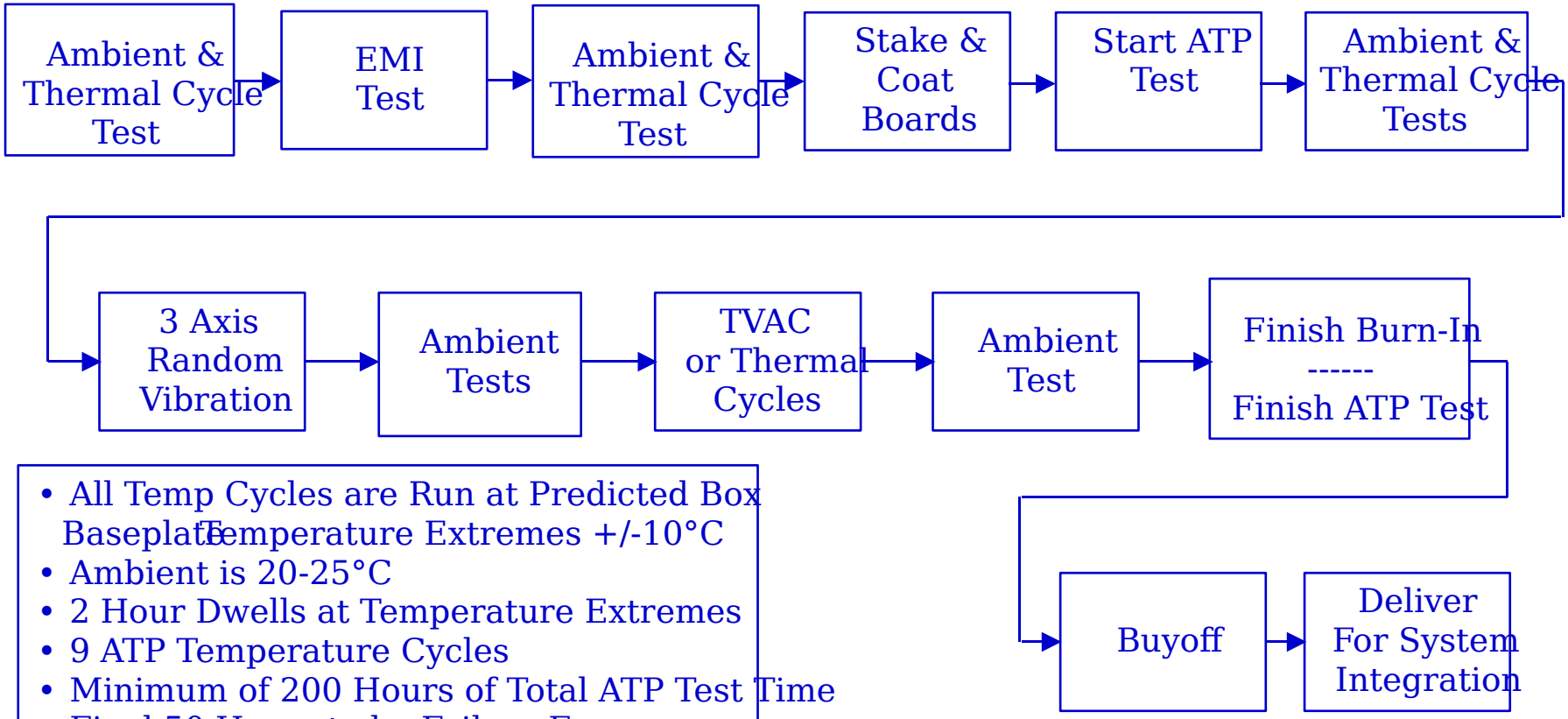
EPS Box Test Program

Fame EPS Test Matrix

Component	200 HR Burn-In	Thermal Cycle	Random Vibration	Acoustic Vibration	EMI/EMC	Thermal Cycle
PCU	Yes	Yes	Yes	No	Yes	Yes*
PDU	Yes	Yes	Yes	No	Yes	Yes*
BCB	Yes	Yes	Yes	No	Yes	Yes*
S/A J-BOX	Yes	Yes	Yes	No	No	Yes*
Solar Array	No	No	No	Yes	No	Yes
Battery	No	Yes	Yes	No	No	Yes*

* At System Level

FAME EPS Box Test Flow



- All Temp Cycles are Run at Predicted Box Baseplate Temperature Extremes +/-10°C
- Ambient is 20-25°C
- 2 Hour Dwells at Temperature Extremes
- 9 ATP Temperature Cycles
- Minimum of 200 Hours of Total ATP Test Time
- Final 50 Hours to be Failure Free
- Static Loads Qualification by Analysis or by Sine Burst Testing

Example Above is For Protoflight Electronics Box